UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

Before the Atomic Safety and Licensing Board

In the Matter of	)	
	)	
PRIVATE FUEL STORAGE L.L.C.	)	Docket No. 72-22-ISFSI
	)	
(Private Fuel Storage Facility)	)	

APPLICANT'S REPLY TO THE PROPOSED FINDINGS OF FACT AND CONCLUSIONS OF LAW OF THE STATE OF UTAH AND THE NRC STAFF ON UNIFIED CONSOLIDATED CONTENTION UTAH L/QQ (SEISMIC)

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25 (Bartlett, Ostadan); Trudeau Section D Dir. at A37; Ebbeson Dir. at A25; Ebbeson Reb. at A3.

F. Section D of Contention L/QQ: Seismic Design and Foundation Stability: Stability Analyses for the Storage Casks

1. Background

R209. The State prefaces its findings on cask stability with statements of general concern voiced by Dr. Ostadan about PFS's reliance on nonlinear analysis for an "unconventional nuclear facility design," lacking any "design redundancies," that is both "unique and unconservative." State F. ¶¶ 248-49. We have already addressed above the State's inaccurate characterization of the PFSF design as unprecedented and unconservative. See Section IV.C.1 above.

R210. Insofar as Dr. Ostadan's statements of general concern relate to adequacy of the Holtec cask stability methodology, we note that Dr. Ostadan provided no testimony concerning the Holtec methodology other than with respect to foundation loading issues discussed above. Furthermore, Dr. Ostadan disclaimed having any expertise on cask stability analyses. See Tr. 10676-77 (Ostadan). Thus, Dr. Ostadan's statements of general concern about the appropriateness of Holtec's analyses discussed in State F. ¶¶ 248-49 have no particular weight. An intervenor's burden of going forward requires more than mere expressions of concern by a non-expert.

R211. The State goes on to refer to the number of ISFSIs licensed to date (23), the total number of dry storage casks of all types currently in use (325); the number of HI-STORM 100 dry storage casks currently in use (12), the lower seismicity of existing ISFSI sites used Holtec casks; and the lack of use of soil cement at ISFSIs elsewhere. State F. ¶¶ 250-51. Based on this recitation of facts, the State requests the Board to find "insufficient evidence that the Staff has licensed free standing, cylindrical dry casks at sites where the design basis ground motion equaled or exceeded 0.7g," and similar such findings of lack of precedence for the PFSF design. State F. ¶ 252. From such findings, the State would have the Board conclude that "PFS has an unconventional design that is unprecedented and unproven with no redundancies," and that, as a result, PFS must undertake "comprehensive analysis and testing . . . to determine whether the HI-STORM 100 casks will excessively slide, uplift, or tipover under the 2,000-year DBE." State F. ¶ 253.

R212. Again, as discussed above, the State's claims as to the uniqueness of the PFSF design are erroneous and have no evidentiary value. The issue here is whether the PFS seismic design adequately protects the public health and safety. To properly challenge the design, an intervenor must identify inadequacies in it, rather than express general concerns about its alleged novelty. Even if such claims were true – which is not the case here – such generalized concerns do not meet an intervenor's burden of going forward.

2. Standard

R213. The State states that the issue is whether "the Applicant has reasonably demonstrated that the HI-STORM cask will not tip over when subject to the proposed design basis earthquake." State F. ¶ 254. It then goes on to ask that the Board review the cask stability analyses performed by the parties with "a certain degree of circumspection." State F. ¶ 256. The State analogizes nonlinear analysis to the use of a "black box." Id.[109] The State also makes reference to statements by

[109] The State's source for that quote, however, is Dr. Ostadan, whose lack of expertise on the subject has been noted above.

Dr. Cornell and Dr. Soler concerning the use of computer models in an attempt to depict non-linear analyses as inherently unreliable. Id. The record does not, however, support the State's attempt to denigrate the reliability of nonlinear analyses.

R214. Specifically, the State claims that "Dr. Cornell emphasized that nonlinear analyses provide information and insight, but a critical question is 'how much information to take from [nonlinear analysis] away towards making subsequent design judgments.'" Id. Contrary to the implication of the State's proposed finding, Dr. Cornell testified that the Holtec and Sandia analyses had served to reduce uncertainty in the estimation of cask performance. Tr. 8022 (Cornell). Indeed, in responding to a question from Judge Lam on whether non-linear analysis is generally suspect or "unreliable," Dr. Cornell's response was emphatic: "Absolutely not. No. Typically they are reliable." Tr. 8010 (Cornell).

R215. Dr. Cornell went on to say that because non-linear analysis are not as simple as linear analyses, they do "depend to a greater extent on the expertise of the user than does a linear analysis . . . ." Id. at Tr. 8011. In this respect, we note that Drs. Singh and Soler have almost 20 years of experience doing nonlinear analyses for spent fuel racks and storage and transportation casks. Singh/Soler Dir. at A162. The computer code used to perform nonlinear analyses of the storage casks at the PFSF, DYNAMO, has been validated in accordance with NRC quality assurance requirements to provide accurate results. Singh/Soler Dir. at A30, A113, A118, A133-134. Similarly, the nonlinear analyses conducted by Sandia for the PFSF are the culmination of three years of extensive effort resulting in "a huge accumulation of experience" in performing nonlinear analyses for different dry cask storage systems under various conditions and assumptions so as to provide confidence in the Sandia predictions for the PFSF. Tr. 6987 (Luk). In contrast, the State's witness, Dr. Khan, had never done this type of analysis before. See PFS Exh. 88 at 23-24, 67-69; Tr. 7136, 7154-55 (Khan).

R216. The State also refers to Dr. Cornell's confirmation of Judge Farrar's observation that it is "possible to become too enamored of the models and lose sight of making sure they are anchored in reality." Tr. 8024 (Cornell). However, Dr. Cornell was speaking broadly in terms of models as he had just noted that "[a] shake table is another model." Id. at 8023. Moreover, there is no suggestion in Dr. Cornell's testimony (nor does the State cite to any) that he had any such concerns with respect the Holtec or Sandia models. Id. at 8022-24.[110] Again, we find this general concern is far more applicable to the cask stability analyses conducted by the State's expert than to those performed by Holtec, whose model has been validated per the applicable nuclear standards and which has undergone numerous NRC license application reviews.[111] In contrast, the model used by the State's expert was not validated and provide results that the State's own experts agree are not "anchored in reality." PFS F. ¶¶ 221, 230-234.

R217. The State also cites testimony by Dr. Soler to the effect that "you can't say, because the computer program says it's so, that means it's so." State F. ¶ 256, quoting Tr. 9775 (Soler). The State, however, completely distorts the meaning of Dr. Soler's statement. Dr. Soler provided this testimony in describing a professional seminar on the performance of HI-STAR casks. Tr. 9773-75 (Soler); State Exh. 199. At the presentation, Dr. Soler contrasted the results obtained using two

[110] Dr. Cornell reviewed both the Holtec and Sandia methodologies and identified no concerns with either. Tr. 7973-74, 7987-88 (Cornell).

[111] As discussed below, we find the State's challenges to the Holtec model raised in its findings to be devoid of merit.

computer codes, VisualNastran and DYNAMO, for a loading condition under which DYNAMO had predicted large cask rotations (on the order of 20 degrees), but not cask tipover. Id. In contrast, VisualNatran (a computer code capable of handling large deflections) did show tipover under the same conditions. Id. The point made by Dr. Soler, both in the presentation and his testimony, was that one had to be aware of the limits of applicability of computer codes and should not use a code beyond those limits. Id. At no time in his testimony did Dr. Soler express the view that the nonlinear analysis performed by Holtec gave unreliable results.

R218. Indeed, Holtec has validated and successfully used DYNAMO many times to model small deflections. Additionally, the results of both the DYNAMO and VisualNastran codes (further confirmed by Sandia's model) show that the 2,000-year return period DBE results in small displacements of the casks at the PFSF. Thus, DYNAMO was an appropriate tool for analyzing cask stability at the 2000-year ground motion level for the PFSF.

R219. In contrast, the State's witness used what he acknowledged was a small deflection program that produced unrealistically large displacements, which he nevertheless claimed to be valid results. Tr. 7173-74 (Khan). Unlike Holtec, the State witness had not previously used his model to predict displacements of large free standing bodies, nor had he ever validated the model in accordance with NRC quality assurance requirements. PFS F. ¶¶ 222-26. In such circumstances, the general caution sounded by Dr. Soler is appropriate and directly applicable to the results of the State's nonlinear analyses.

3. Expert Witness Conflict of Interest

R220. The next section of the State's proposed findings (State F. ¶¶ 257 through 260) is entitled "expert witness conflict of interest." We are unaware of any legal doctrine defining such a term. Nor does the State enlighten us of any legal doctrine underlying its use of that term, which typically implies that a party has assumed conflicting obligations, a situation clearly not present here. Rather, it appears from the context of the State's proposed findings ~~is~~ that Drs. Singh and Soler are biased because their company, Holtec, has "the potential to sell 4,000 storage casks and other products such as the HI-TRAC canister cask to the PFS project." State F. ¶ 258. The legal bases for this claim of bias were evaluated and rejected above as non-meritorious. <u>See</u> Section II, <u>supra</u>.

4. Holtec's Experience in Performing Non-Linear Cask Stability Analyses

R221. The State next claims that Drs. Singh and Soler lack "direct, relevant experience" on cask stability analysis because they have never performed non-linear analyses for a free standing cask system supported by soil cement or cement-treated soil in a high seismicity site, that is, one having exactly the same attributes as those for the PFSF site. State F. ¶¶ 262-63. We have already discussed above why this argument is nonsensical. <u>See</u> Section II above. As acknowledged by Dr. Mitchell in a different context, if "we get specific enough, in essence everything is unique." Tr. 11263 (Mitchell).

R222. In this same vein, the State's claims that the extensive modeling that Holtec has done of free standing spent fuel racks is inapplicable because of physical differences between spent fuel racks and spent fuel storage casks. State F. ¶ 264.[112]

[112] The State cites Dr. Khan's testimony as support for its claim that Holtec's modeling of spent fuel racks lacks relevance. However, Dr. Khan never previously performed the modeling of spent fuel storage casks and had in only one instance performed a highly simplified modeling

However, both involve the modeling of large freestanding objects with frictional resistance between the object and the surface on which they stand. Singh/Soler Dir. Test. at A28. Indeed, a licensing board found the Holtec model to be "a non-linear dynamic model [that] "appropriate[ly] consider[s]. . . movement of the fuel assemblies, frictional resistance at the base of the rack, rack sliding and rocking behavior, rack uplift and subsequent impact on the bearing plate, and rack impacts with adjacent racks and pool walls." Pacific Gas and Electric Co. (Diablo Canyon Nuclear Power Plant, Units 1 and 2), LBP-87-25, 26 NRC 168, 191 (1987).[113] Thus, employing the same basic modeling techniques and computer code (DY-NAMO), Holtec's extensive modeling of spent fuel racks does constitute a relevant experience base for the modeling of freestanding spent fuel storage casks.

R223. The State next claims, citing Dr. Soler's testimony at Tr. 5996-97, that he and Mr. Bullard of Holtec have only "limited" experience in calculating soil springs and dampers for analyzing soil dynamics and foundation design. State F. ¶ 266. Dr. Soler testified that he and Mr. Bullard had no expertise in the design of foundations and soils. However, as Dr. Singh explained, once the soil characteristics are developed by others, Holtec analyzes the interaction between the soil and the structure attached to it using classical mechanical techniques. Tr. 5997-98 (Singh). With respect to the choice of soil springs and dampers for its analyses, Holtec used the formula in the industry standard ASCE 4-86, "Seismic Analysis of Safety Related Nuclear Structures and commentary," for computing soil

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of the displacement of spent fuel racks. Tr. 7174-47 (Khan); PFS Exh. 88 at 37-38. Thus, Dr. Khan is not in a position to make such a judgment.

[113] Holtec supplied the spent fuel racks for Diablo Canyon and performed the dynamic analyses for them. Singh/Soler Dir. at A28; see also Tr. 7144-47 (Khan). The State tries to distinguish Holtec's analysis of spent fuel racks as irrelevant, State F. ¶ 264, but the finding of the licensing board quoted above shows otherwise.

springs and dampers. Singh/Soler Dir. at A32; see also State F. ¶ 268, n.42. Dr. Wen Tseng, who has extensive soil-structure-interaction ("SSI") experience, further confirmed that the formulas used by Holtec to develop the soil springs and dampers for its cask stability analyses are derived from a well-recognized technical treatise. Tseng Reb. At A8. Thus, Holtec has the expertise needed to perform its soil-structure interaction analyses.

R224. It is important to note that the State has alleged no deficiencies with respect to the soil spring and damper calculations performed by Holtec as part of its cask stability analyses (other than those discussed and resolved in Section IV.D above).[114] Thus, the State's generalized claim of lack of experience of Dr. Soler and Mr. Bullard with respect to the calculation of the appropriate soil spring and dampers to use in the Holtec cask stability analyses is irrelevant, since there are no issues in dispute to which it would relate.[115]

5. Applicant's Cask Stability Analyses

R225. The next section of the State's proposed findings describes the cask stability analyses that Holtec performed for the 2,000-year DBE and those described in the Holtec "PFSF Beyond Design Basis Scoping Report." ("Holtec Beyond Design Basis Report"). State F. ¶¶ 268-72.[116] The State suggests that the lower bound

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[114] As discussed in Section IV.D the State raised certain issues challenging the ~~manner in which Holtec applied the formula in ASCE 4-86.~~ assumption of pad rigidity underlying the choice of soil spring and dampers. State F. ¶ 190.

[115] As set forth in Section II above, the State would have the burden of coming forward with specific claims of deficiencies, which it has not.

[116] The State would have the Board find that "[i]n an attempt to thwart the State's criticisms of the Holtec 2,000-year report, the cask vendors performed sundry computer runs and animations not with DYNAMO but with a different computer code, VisualNastran 2001. Applicant Exh. 86 at 14, Tr. (Soler) at 9749." State F. ¶ 270. However, the cited testimony of Dr. Soler concerns the simulations in PFS Exh. 225 in which Holtec conducted several runs using VisualNastran seeking to reproduce the model used by State witness Dr. Khan in his analysis. Tr. 9748-49 (Soler). Rather, than "thwart" the State's criticisms, those computer simulations showed that results of Dr. Khan's were not reproducible using a program capable of modeling

soil parameters used by Holtec in its Beyond Design Basis Report did not include the effects of soil cement. Id. at ¶ 271. However, it is undisputed that the lower bound soil properties for the PFS site (as well as the best estimate and upper bound soil properties) incorporated the effects of soil cement and cement-treated soil to be used at the PFS site. Singh/Soler Dir. at A31-A34. The State raised no issues concerning these soil properties.

6. Alleged Unreliability and Uncertainty of PFS's Cask Stability Analyses: Holtec's Use of DYNAMO (Responding to State F. ¶¶ 273-287)

a) Technical Arguments Made in Support of the State's Claim

R226. The State goes to great lengths to argue that DYNAMO has "questionable reliability at sites with high seismic ground motions." State F. ¶¶ 273-287. The State's claim is premised on repeated cautions by Dr. Soler that predictions of large displacements or cask rotations (on the order of 15 degrees or more) resulting from the use of a small deflection code may not be accurate because the code's capability is being exceeded. State F. ¶ 274. According to the State, Dr. Soler's cautions call into question the validity of the DYNAMO results for the 2,000-year DBE because DYNAMO is admittedly a small deflection code.[117]

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large deflections. Page 14 of PFS Exh. 86C simply identifies VisualNastran as the computer code used for the computer runs in PFS Exh 86C. The purpose of the computer runs was to "provide bounding simulations" that would envelop the "potential effect" of the issues postulated by the State. Id. at 5.

[117] The State would have the Board find "no evidence to support Dr. Soler's confidence in DYNAMO producing accurate results in this case." State F. ¶ 274. Such a finding is erroneous and a non-sequitor. Dr. Soler's testimony quoted in support of this sweeping conclusion only stands for the proposition, often repeated by Dr. Soler, that a large deflection obtained from a code written for small deflections may be erroneous because the code's capability is being exceeded. That does not undercut the accuracy of results achieved by using a code within its area of applicability.

R227. In making this argument, the State completely ignores that the DYNAMO results for the 2,000-year DBE show cask displacements of only a few inches and a maximum cask rotation of 1.026 degrees. Singh/Soler Dir. at A36. These are very small displacements and rotations, well below the 15-degree or larger rotations that Dr. Soler referred to as comprising large displacements. Further, Dr. Soler explained why at such small rotations the predictions of DYNAMO remain mathematically valid. Tr. 6100-02 (Soler). The State totally ignores this testimony of Dr. Soler's and cites no evidence that would tend to show that the small displacement results obtained for the 2,000-year PFSF DBE are beyond the capability of the DYNAMO code.[118]

R228. The State points Dr. Soler's seminar presentation, already discussed above, of a HI-STAR cask using VisualNastran for conditions under which DYNAMO had predicted large cask rotations (on the order of 20 degrees) but not cask tipover. The State claims that DYNAMO's failure to predict tipover in that instance, which was shown to occur using VisualNatran, shows the inappropriateness of using DYNAMO for the 2,000-year DBE. State F. ¶ 276. However, the State totally ignores that DYNAMO in that case had predicted large cask rotations of 20 degrees (as shown in State Exh. 199 at 8), whereas for PFS the maximum rotation shown by DYNAMO is only 1.026 degrees. Singh/Soler Dir. at A36.[119] As explained by Dr. Soler, the very purpose of using VisualNastran in that presentation

[118] The State would have the Board find "no evidence that the rotational limits of DYNAMO are not exceeded when evaluating ground motions equal to or greater than 0.7g, the 2,000-year earthquake at PFS." State F. ¶ 275. In proposing such a finding, the State grossly ignores Dr. Soler's testimony. In fact, a correct finding would be the opposite: there is no evidence that the rotational limits of DYNAMO are exceeded under DBE ground motions.

[119] The large rotations exhibited by the HI-STAR cask in the analyses discussed in Dr. Soler's presentation are due to the different physical configuration of both casks. For example, the HI-STAR cask is 83 inches in diameter at its base as opposed to 133 inches for the HI-STORM, and is therefore less stable. Tr. 9785-86 (Soler).

was to demonstrate that when a small deflection program predicts large displacements, a modeler needs to be cognizant that the capability of the program may have been exceeded and that the results may not be accurate. Tr. 9773-75 (Soler).

R229. Therefore, the Holtec seminar demonstration cited by the State is inapposite for Holtec's analysis using DYNAMO for the 2,000-year PFSF DBE. The ability of DYNAMO to make predictions for the PFSF 2,000-year DBE is confirmed by Holtec's using VisualNastran to model one of the cases for 2,000-year PFSF DBE that had initially been modeled using DYNAMO. The results obtained by Holtec using VisualNastran showed cask displacements of only a few inches and cask rotations on the order of one degree similar to those obtained by DYNAMO. PFS Exh. 86C at 20-21.

R230. The appropriateness of using DYNAMO for the cask stability analysis of the 2,000-year DBE at the PFSF is further supported by the results of the Sandia simulations for the PFSF 2,000-year DBE, which similarly predicted maximum cask displacements on the order of a few inches and minimal cask rotations of less than one degree. Staff Exh. P at 30. Thus, there is no technical merit to the State's claim that DYNAMO gives unreliable predictions of the performance of the HI-STORM storage casks for the PFSF 2,000-year DBE.

b) Non-Technical Arguments Advanced by the State

R231. The State also raises numerous non-technical objections to the use of DYNAMO to analyze the behavior of the PFSF casks. State F. ¶¶ 277-287. The State argues that there was insufficient opportunity for the Board and the parties to independently determine the reliability of the DYNAMO code because (1) the DYNAMO code itself was not provided to the Board and the parties (due to its being proprietary Holtec information), and (2) certain calculations performed by Holtec supporting the use of DYNAMO at the PFSF have not been placed into evidence. In addition, the State claims that (3) no documentary evidence or sufficient other evidence has been proffered demonstrating the claimed validation of the DYNAMO code, nor (4) was any evidence submitted showing whether, and on what basis, the NRC accepted the use of DYNAMO. These arguments not only misconstrue the applicable evidentiary and burden of proof standards, discussed in Section II above, but also completely ignore noncontroversible evidence in the record.

R232. First, the State suggests that it could not test the reliability of the DYNAMO code because the code had not been produced to the State and its cross-examination of the Holtec witnesses on the reliability of the DYNAMO code was hampered by the unavailability of the code. State F. ¶¶ 277, 279.[120] In fact, the State never requested a copy of DYNAMO during discovery or even during the hearing. The State received Holtec's calculations for the PFSF in the course of discovery for this proceeding as well as part of its regular receipt of PFS's licensing submittals to the NRC Staff.[121] Additionally, the State conducted two depositions of Drs.

[120] We note that the capability of DYNAMO as a small deflection program to adequately model the PFSF 2,000-year DBE was first raised as an issue by the State in its pre-filed testimony on April 1, 2002. See Khan/Ostadan Dir. at A11, A26. There is no specific reference to this claim in the Unified Contention Utah L/QQ. See PFS Exh. 237.

[121] The Applicant has provided the State of Utah with pertinent calculations throughout the proceeding. By the State's admission, the State received proprietary portions of Holtec Calculation Packages "under a confidentiality agreement on November 13, 1977." See State of Utah's Request for Consideration of Late-Filed Contentions Utah EE and FF, December 23, 1997, in which the State of Utah filed Late-Filed Contention Utah EE challenging Holtec's cask stability analysis in HI-971613, Multi-Cask Seismic Response at the PSF [sic] ISFSI. Subsequently, PFS voluntarily committed to providing the State and other parties in the proceeding with any correspondence from PFS to the NRC. See Official Transcript of Proceedings, Private Fuel Storage, L.L.C. – Pre-Hearing Conference, page 831 (Thursday, January 29, 1998). Under this arrangement the State was copied on PFS submittals to the NRC Staff, including submittals of Holtec calculations. See, e.g., PFS Exh. NN (August 7, 2001 PFS letter submitting Holtec calculation to NRC Staff, copying the State). In this respect, the State acknowledged its receipt from PFS of many seismic-related Holtec calculations, some proprie-

Singh and Soler on cask stability analyses performed by Holtec for the PFSF, which included Holtec's use of DYNAMO for its design basis calculations.[122] To the extent that the State believed that it needed DYNAMO or any other technical documents or information from PFS necessary for the preparation of its case, the State could and should have requested the specific information from PFS as part of discovery. The State has done so in the past to obtain information it deemed necessary for the preparation of its case, including situations involving proprietary computer codes.[123] The short of the matter is that the State never got a copy of DYNAMO because it never asked for it.[124] It is too late by far for the State to complain.

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tary and some non-proprietary, as a basis for its filing of late contentions on April 23, 2001. See Exhibit 1 to State of Utah's Request for Permission to File Late Filed Geotechnical Contentions Within Thirty Days of Receipt of Calculations Supporting License Amendment (April 23, 2001). Finally, Holtec documents were provided during the course of discovery.

[122] Deposition of Krishna P. Singh and Alan I. Soler on Utah Contention L, Part B, November 15 & 16, 2002. See State Exh. 121; Deposition of Krishna P. Singh and Alan I. Soler on Utah Contention L/QQ, March 6, 2002. See State Exh. 120.

[123] In connection with the litigation of Utah H (Inadequate Thermal Design), the State requested a copy of the software code FLUENT. As this was a proprietary code of the computer vendor, Holtec informally informed the State that the code was "not capable of being copied...to use on other computers." See Applicant's Response to State of Utah's Proprietary and Non-Proprietary Motion to Compel Applicant to Respond to State's First Set of Discovery Requests at 10, n20 (May 7, 1999). Unsatisfied with this response, the State submitted a motion to compel. State of Utah's Proprietary Motion to Compel Applicant to Respond to State's First Set of Discovery Requests Regarding Contention H (April 30, 1999). Eventually the matter was resolved. Thus; even assuming that PFS and Holtec would have refused a request by the State to produce the DYNAMO code, the State was certainly familiar with the process for asking the Board to compel PFS to do so.

[124] The State suggests that DYNAMO was not available because "Holtec holds its DYNAMO code as proprietary information. . . ." State F. ¶ 277. However, as acknowledged by the State, it has entered into a confidentiality agreement under which it has obtained proprietary Holtec information. See State of Utah's Request for Consideration of Late-Filed Contentions Utah EE and FF at 1 (December 23, 1997). Therefore, the State's reference to the proprietary nature of certain information thereby suggesting that it was somehow precluded from obtaining it is wholly unsupportable.

R233. Second, the State also suggests that the Board cannot make a finding about the adequacy of DYNAMO absent the formal introduction into evidence of the underlying supporting Holtec calculations or the DYNAMO code itself so that the Board can make its own evaluation of the reliability and limits of DYNAMO. State F. ¶ 277. As discussed earlier, such is not the role of the Board in this proceeding absent a specific and timely challenge to the code itself. See Section II above.

R234. The State specifically alleges that the supporting calculations for contact spring stiffness used in the Holtec analyses are not in the record. State F. ¶ 278. This is totally wrong. While the contact spring stiffness computations used in Holtec's 2,000 year cask stability analysis for the PFSF are not included in the cask stability analysis report (State Exh. 173), they are included in a prior calculation, Holtec Report HI-971631 – the very same calculation that the State of Utah sought to challenge in Late-Filed Contention Utah EE.[125] Moreover, the relevant portion of Holtec Report HI-971631 setting Holtec's computation of the contact spring stiffness for the DYNAMO model was introduced into evidence as PFS Exhibit 226.[126] Moreover, Drs. Singh and Soler orally testified to the methodology Holtec used to compute the contact spring stiffness in PFS Exh. 226 and to the consistency of its methodology with guidance provided by the ANSYS training manual. Tr. 9622-26 (Singh/Soler). The State chose neither to cross-examine

[125] State Exhibit 173 states that the input data for the spring constants used in State Exhibit 173 (with the exception of the soil springs) is "identical to that employed in the previous analysis and is fully documented in [Holtec Report HI-971631]." State Exh. 173 at 7, 12. State of Utah's Request for Consideration of Late-Filed Contentions EE and FF dated December 23, 1997. See also

[126] PFS Exhibit 226 is the portion of Appendix C to Holtec Report HI-971631 (the original Holtec cask stability calculation for the deterministic earthquake) entitled "Calculation of Spring Constants for HI-STORM Seismic Analysis in Storage Facility."

Drs. Singh and Soler on PFS Exhibit 226 or their related oral testimony nor to provide any testimony in rebuttal. See Tr. 9727-80. (State cross-examination of Dr. Singh and Dr. Soler) and Tr. 9791-98 (State rebuttal by Dr. Khan). Therefore, the State may not be heard now about its inability to test the reliability of the contact stiffness computations.

R235. Moreover, nothing prevented the State from cross-examining Drs. Singh and Soler on the contact stiffness computations, even assuming the computations had not been introduced into evidence. Given that the State's Late-Filed Contention Utah EE was based on the very calculation from which PFS Exh. 226 was excerpted the calculation was certainly available to the State for use in cross-examining Drs. Singh and Soler on the reliability of their contact spring computations for use with DYNAMO.[127]

R236. Third, the State's arguments concerning the lack of evidence of DYNAMO's validation and its acceptance by the NRC Staff are likewise without merit. As an initial matter the State is totally mistaken in its claim that PFS "failed to proffer supporting documentation from the DYNAMO training manual," from which allegation it requests that the Board find that "not a scintilla of evidence has been offered by the Applicant that DYNAMO has been validated by the training manual." State F. ¶ 282. Contrary to the State's claim, the Applicant introduced as PFS Exhibit RR a portion of the manual validating DYNAMO against a classical

[127] Likewise, the State cites Dr. Singh's testimony "that DYNAMO has 'been used in over a thousand discrete structures, qualifying them'" and that "DYNAMO is a 'well tested program.' Tr. (Singh) at 6099-6100." State F. ¶ 280. The State goes on to bemoan the fact that "[t]he parties offered no evidence with respect to the type of 'discrete structures' qualified by DYNAMO and how those DYNAMO analyses are relevant to this case given the unique and unprecedented design posed by PFS." State F. ¶ 280. This proposed finding is inexplicable. State counsel was present at the hearing in which Dr. Singh gave that testimony. The State chose not to question Dr. Singh on these matters. Complaining about the absence of evidence that could have been elicited in cross-examination just does not make any sense.

solution to ensure that DYNAMO correctly "modeled the 'stick-slip' nature of frictional resistance." Singh/Soler Dir. at A150; see also id. at A134.[128] Again the State failed to cross-examine Drs. Singh and Soler on this portion of the manual even after Dr. Soler had testified about it at the hearing, see Tr. 9647-48 (Soler); nor did the State question the Holtec witnesses about the validation process that Holtec had undergone for the DYNAMO code.

R237. For the same reason, the State's analogous claim that no evidence was offered to demonstrate the relevance of the classical problems to the unique matter at issue is likewise completely inaccurate. State F. ¶ 284. Drs. Singh and Soler referred to the classical solution introduced as PFS Exh. RR as suitable for testing the ability of a model "to predict the dynamic behavior of free standing bodies in the presence of friction." Singh/Soler Dir. at A134. Indeed, using this classical problem, they demonstrated that Dr. Khan's model would not accurately predict the dynamic behavior of free standing bodies in the presence of friction. Singh/Soler Dir. at A148-A151. Despite this clear relevance to both the validation of the DYNAMO code and direct challenge to Dr. Khan's model, the State chose not to cross-examine Drs. Singh and Soler on this testimony.

R238. Moreover, contrary to the State's claims, Drs. Singh and Soler testified how DYNAMO was validated. It was done "in a manner consistent with ASME NQA-2a-1990, Part 2.7, 'Quality Assurance Requirements of Computer Software for Nuclear Facility Applications.'" Singh/Soler Dir. at A133. ASME NQA-2a-1990 mandates that a computer code be benchmarked against classical solutions and peer computer codes to the extent possible using appropriately selected test problems so as to establish the suitability and stability of the code for the class of

[128] The pre-filed testimony refers to the manual as the "Validation Manual." Id.

problems being analyzed. Id. at A134. Holtec did both. Id. at A30, A133.[129] Moreover, the record further shows that the State freely questioned Drs. Singh and Soler about the validation of DYNAMO at their deposition. PFS Exh. 224 at 32-36; see also State Exh. 220 at 32. Additionally, the State was advised that Holtec's validation report for DYNAMO had been filed as a "formal document" with the NRC and was available from NRC the public document room. Id. The State could have cross-examined on all or any of these matters at any point during Holtec's lengthy testimony at the hearing.[130]

R239. The State questions whether the Staff has accepted Holtec's validation of DYNAMO and if so the basis of the Staff's acceptance. State F. ¶ 281. It is clear that the Staff has accepted the use of DYNAMO for both wet and dry storage. This is evident by its approval of numerous applications that DYNAMO supported. Singh/Soler Dir. at A28. The Staff could not have fulfilled its independent review function without being satisfied about the use of DYNAMO, e.g., as used in the cask stability analysis for the PFSF. The basis of the Staff's acceptance of DYNAMO is irrelevant.

[129] The State seeks to discredit Holtec's validation of DYNAMO against the ANSYS computer code based on, reference by Dr. Singh where Holtec had found ANSYS to have given inaccurate results. State F. ¶ 283, citing Tr. 6099 (Singh). From this single reference, on which the State never followed up on and never tied in any way to the validation of DYNAMO, the State request the Board to find that the comparison between DYNAMO and ANSYS is unreliable. The record simply does not support the assertion. The point being made by Dr. Singh was that given the long track record and capability of DYNAMO, Holtec had been able to identify this instance when ANSYS did not provide reliable results. Contrary to the State's proposed finding, this testimony supports the ability of DYNAMO to provide valid results.

[130] Dr. Singh and/or Dr. Soler testified on April 30, May 1, June 4, June 5, and June 8, 2002. Dr. Soler was physically present in the hearing room and was in fact available to answer questions even when he was not on the stand. See, e.g., Tr. 6945-48 (Dr. Soler providing information during cross-examination of Dr. Luk); Tr. 7589-98 (Dr. Soler providing information during cross-examination of Dr. Ostadan).

R240. The function of the Board is to resolve specific challenges raised to the adequacy of an applicant's license application. In that context, the Board exercises its independent technical judgment with respect to the challenges raised by intervenors. The Board is not obligated, however, to let an intervenor stay silent during the pre-hearing process, the filing of testimony, and at the hearing itself and raise an issue for the first time in its proposed findings.

R241. PFS has clearly specified the basis on which DYNAMO was validated and explained why it is reasonable to conclude that the code can handle the deflections resulting from the 2,000-year DBE at the PFSF. Thus, the clear weight of evidence in the record shows that DYNAMO has been validated and can handle the deflections shown to occur for 2,000-year DBE at the PFSF.

7. Testability of Holtec's VisualNastran Results (Responding to State F. ¶¶ 288-292)

R242. The State raises no challenges to the capability of the VisualNastran code to model cask stability at the PFSF. Rather, the State focuses its criticism on what it claims are the "testability" limitations of Holtec's VisualNastran results, arguing that it lacked an opportunity to "test" the reliability of Holtec's VisualNastran results in cross-examination. State F. ¶ 288. The State makes two arguments in this respect, neither of which have merit.

R243. First, the State claims that no document in evidence lists every input value for each of the VisualNastran simulations. State F. ¶ 289. That is simply incorrect. The State cites Tr. 5791 (Soler) and 5796 (Singh) for the proposition that no such listing exists. That was true at the time the testimony was given. However, such a compilation was subsequently prepared by Dr. Soler – after extensive discussion among the Board and the parties – and was supplied to the State.[131] The State itself moved the this compilation into evidence as State Exh. 179.[132] It is incomprehensible how the State can now assert that such evidence does not exist.

R244. The other claims raised by the State with respect to the "testability" of the VisualNastran inputs are similarly lacking in merit. The State claims that Dr. Soler could not provide the critical damping used for case 11. State F. ¶ 289. As explained by Dr. Soler, the formulas for damping provided by ASCE Standard 4-86 (which as discussed earlier are based on well-recognized sources) are not developed based on a percent of critical damping. Tr. 5788-89 (Soler). Thus, Dr. Soler provided the actual damping input values used in the run and similarly provided the actual damping input values used for the other runs as well. See State Exh. 179; PFS Exh. 86D. The State does not refer to this information. PFS's provision of the actual damping input values is a complete answer to the State's complaint.

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[131] There was extensive discussion among the Board and the parties as to how the VisualNastran input parameters could be put "on the record" so the State would be "in a position to cross examine" with respect to them. Tr. 5792-804; 5850-55. Dr. Soler missed part of the hearing in order to prepare a table of the input parameters for two of the computer runs, cases 8 and 11, which was provided to the Board and parties as PFS Exh. 87. Tr. 5856-58, 5868-73. Subsequently, the State requested a similar compilation of the input data for the remaining nine computer runs that were part of the Holtec Beyond Design Basis Report (PFS Exh. 86C) to which PFS and Dr. Soler agreed. Tr. 5974. The understanding and intent was that State would review these materials and conduct whatever cross-examination it deemed appropriate at a later time. Tr. 5975. Dr. Soler did compile the additional input information, as well as the displacements for cask 1 for the additional runs, and this information was provided to the State and the Staff. Tr. 6480-81

[132] The State moved for the admission of State Exh. 179 after using it during cross-examining Dr. Luk but admission was deferred. Tr. 6941-54. The exhibit was subsequently discussed in a colloquy between Drs. Ostadan and Soler, and following this discussion, it was admitted into evidence. Tr. 7589-98. Although the State received the compilation of the input data prepared by Dr. Soler, used it to cross-examine other witnesses, and had it admitted into evidence, the State chose not to cross-examine Dr. Soler on the data compilation. Thus, both the Holtec Beyond Design Basis Report and the corresponding simulations were admitted into evidence without further cross-examination. Tr. 10549-54.

R245. The State also alleges that Dr. Soler was "unaware" of the equations for equilibrium for rigid bodies built into the VisualNastran code. State F. ¶ 289. However, the question put to Dr. Soler was how a particular figure showing the casks in motion "was modeled mathematically," to which Dr. Soler replied "the equations for equilibrium of rigid bodies [are] built into the code. I do not external[ly] model anything mathematically." Tr. 5967-68 (Soler). Thus, Dr. Soler did not say he was "unaware" of the equations for equilibrium of rigid bodies, which the record reflects are well known by him as well by the various testifying witnesses on this matter.

R246. The State criticizes Dr. Soler and the VisualNastran simulations because Dr. Soler did not have the computer track and record the data on cask displacements for each cask, but only one of them, and chose to depict the displacements of the others visually using the simulation.[133] State F. ¶ 288. Dr. Soler explained, however, that the evaluations were a "scoping analysis," as the full title of the Report reflects[134] and the primary purpose was to see whether "at the end of the earthquake do we have eight casks "still standing." Tr. 5771 (Soler).

R247. Thus, the focus of the analysis was not on the specific measurements of the displacement of the casks. Id. Accordingly, as Dr. Soler explained, he had initially set the computer to record the measured displacements for cask 1 for all of the 11 cases, which remained stored in the computer so that it could be retrieved from the computer.. Tr. 5762-64 (Soler). At the request of the Board, Dr. Soler produced a table

[133] The State also criticizes Dr. Soler because he did not have some information available (e.g., numerical data for the cask displacements) at his fingertips. State F. ¶ 288. We find this criticism to be unfounded in view of Dr. Soler's explanation of the purpose of the study as discussed in the text.

[134] The full title of PFS Exh. 86C is "PFSF Beyond Design Basis Scoping Analysis."

showing the cask displacements and angle of rotation for cask 1 for all the 11 runs of the Holtec Beyond Design Bases Report. Tr. 5773-76 (Soler). As Dr. Soler explained, obtaining displacement for all casks would take a significant amount of time, and the Board decided to have Dr. Soler produce the information for cask 1 already stored in the computer, and have more steps taken later to obtain measured displacement data on additional casks if the parties or Board deemed that necessary. Tr. 5773-76. The State did not pursue this matter further. It cannot complain now that the data are unavailable.[135]

R248. It is difficult to imagine how the lack of detailed recorded information on the other casks could have restricted the State's ability to cross-examine Holtec on its results. The VisualNastran computer runs were beyond-design basis scoping analyses whose primary function was to determine whether the casks would tip-over under the 10,000-year earthquake event under various bounding, worst case assumptions. Tr. 5771 (Soler); Singh/Soler Dir. at A112-A121. Another purpose was to establish whether the 2,000-year runs using VisualNastran would provide responses similar to those obtained with DYNAMO for the 2,000-year DBE – i.e., inches of displacement not feet of displacement. PFS Exh 86C at 20-21. Both of these points are evident from the simulations. Thus, the points for which the computer cases were offered did not require detailed results for each cask. Since

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[135] The State also complains that Dr. Soler did not know the "inner workings of the VisualNastran" program. State F. ¶ 288. The only inner working that the cited testimony shows that Dr. Soler could not respond to exactly was how VisualNastran varied the input for a random coefficient of friction. Tr. 6019-21 (Soler). This is not significant, however, for Dr. Soler testified that he had reviewed the VisualNastran validation manual comparing results derived from the VisualNastran code to classical solutions in the literature and that he modeled a classical problem using VisualNastran demonstrating good agreement between the VisualNastran and the classical solution. Tr. 6051-54 (Soler).

in none of the runs did the casks slide a great distance or approach the point of tipping over, the magnitude of each cask's displacement is irrelevant.

R249. For the same reasons, the State's objections to the visual simulations are lacking merit. The State claims that without supplemental data the "animations merely represent one analyst's simulation of cask behavior." State F. ¶ 290. This characterization, however, is completely erroneous. They are computer-generated visual representations of the results of the computer analysis.[136] As explained by Dr. Soler: "these videos were not created outside the program, they are part of the program, and they use the results as they are calculated." Tr. 5756-57 (Soler). Therefore, they are only a visual portrayal of the numerical computations made by the VisualNastran code for the input parameters used, and not some abstract "simulation" produced by Dr. Soler. As stated, the points for which PFS relies on the simulations are (1) VisualNastran and DYNAMO provide comparable results for the 2,000-year DBE and (2) VisualNastran shows that the casks do not tip over. Establishing those points, or examining Holtec on them, does not require the quantitative data on cask displacements. Therefore, the State's claims are unfounded.[137]

8. Sensitivity of Non-Linear Analysis Input Parameters

R250. In addition to challenging the reliability of the DYNAMO code and the testability of the VisualNastran simulations, the State questions the validity of the results of Holtec's analyses on the asserted grounds that non-linear analyses are highly sensitive to some input parameters. State F. ¶ 294. The State focused on the choice

[136] The only active step by Dr. Soler in preparing the visual simulations was to compress them to real time. Tr. 5758 (Soler).

[137] Similar to DYNAMO, the State raises questions about the Staff's acceptance of Holtec's use of the VisualNastran code. State F. ¶ 292. As with DYNAMO, this issue is inconsequential.

of contact stiffness and damping values as areas of particular sensitivity. State F. ¶¶ 298-353. Contrary to the State's claims, however, the stability of the casks is largely insensitive to changes in contact stiffness and damping. While changes in the input parameters will affect results to some degree, Holtec's analyses under a wide range of input parameter assumptions show that, for the 2,000-year DBE, cask displacements are on the order of inches, not feet, and that even for a 10,000-year beyond DBE, the casks will not tip over. See PFS Exhs. 86C and 225.

R251. The State claims that the acceptance or non-linear cask stability results should depend upon "showing that the data input into the models are reasonably conservative, accurate, and comprehensive." State F. ¶ 294. As set forth below, the input data used by Holtec for its analyses meet this standard.

a) Choice of Contact Stiffness Values

R252. To support its claim that the nonlinear computer analysis of cask stability is highly sensitive to the vertical contact stiffness assumed between the casks and the pads, the State relies solely on the testimony and report of Dr. Moshin Khan. However, Dr. Khan is a novice with respect to modeling large freestanding objects and he has never chosen a contact stiffness for modeling the displacement of a freestanding object. Tr. 7216-17 (Khan); see also PFS F. ¶¶ 222-26.

R253. In an attempt to downplay Dr. Khan's obvious lack of experience, the State claims that Drs. Singh and Soler have never previously chosen a contact stiffness for modeling a free standing cask for ground motions equal to or exceeding those for the 2,000-year PFS DBE. State F. ¶ 301. This comparison is inappropriate for the following reasons:

- First, it is undisputed that vertical contact stiffness is a physical parameter of the objects in contact and their intrinsic material properties. Tr. 9618-

22 (Singh/Soler). Tr. 7242-43 (Khan); Tr. 6809-11 (Luk).[138] Accordingly, the vertical contact stiffness between two contacting objects does not vary as a function of ground motion, and the State's attempt to claim that Drs. Singh and Soler lack experience in choosing contact stiffness values for various levels of earthquake ground motions is irrelevant and without merit.

- Second, Drs. Singh and Soler have chosen contact stiffnesses for analyzing the stability of large free standing objects under a wide-range of seismic ground motions. Singh/Soler Dir. at A27-29. This experience includes high seismic sites, such as Diablo Canyon, where Holtec analyzed the stability of free standing spent fuel racks for earthquakes from the Hosgri fault. Id.; see also Diablo Canyon, supra, 26 NRC at 191.

- Third, Drs. Singh and Soler have shown themselves to be very knowledgeable about contact stiffness. They testified about its mathematical origin, cited authoritative guidance on its use, described solutions to classical problems involving contact stiffness, and referenced various authoritative sources in their testimony. ~~[Add citations.]~~ See, e.g., Tr. 9617-19, 9622-23 (Singh); Tr. 9628-29 (Soler). Dr. Khan did not exhibit any similar knowledge. ~~[Add citations.]~~ See, e.g., Tr. 9382 (Khan). Moreover, Dr. Khan made no reference to any sources on contact stiffness that would support his understanding and application of contact stiffness.

R254. The State notes that Holtec used a single value of 454 x 10^6 lbs per inch as the contact stiffness between the cask and the pad for the 2,000-year DBE using DYNAMO. State F. ¶ 300.[139] The State goes on to quote Dr. Soler (Tr. 6043) as saying: "we got acceptable answers in the 2,000-year return earthquake, so there was no incentive for us there to lower the contact stiffness." Id. However, the context

[138] Citing Dr. Khan, the State states that "local contact stiffness is needed in a mathematical simulation before any sliding occurs." State F. ¶ 298 (citing Khan/Ostadan Dir. at A24). This is true with respect to horizontal contact stiffness necessary for modeling sliding displacement, which the parties' witnesses agree is a mathematical artifice necessary for computer modeling of sliding displacement. Tr. 7214-15 (Khan); Tr. 9652 (Soler). Vertical contact stiffness is, however, a physical property that can be computed. See PFS Exhs. 221 and 226. Dr. Khan does not dispute that vertical contact stiffness is a property of the contacting materials. Tr. 7242-43 (Khan). Unless otherwise stated, our discussion in the text above concerns vertical contact stiffness.

[139] The State claims that Holtec used a value of 464 x 10^6 lbs. per inch as the contact stiffness for 2,000-year DBE analysis using DYNAMO and it also refers to 450 x 10^6 lbs. per inch contact stiffness. State F. ¶¶ 302, 325. The actual number is 454 x 10^6 lbs. per inch. Singh/Soler Dir. at A138, which we will use throughout.

of Dr. Soler's statement was that, while the "actual contact stiffness is indeed very high," the use of high contact stiffnesses can lead to excessive computation time. Accordingly, as explained by Dr. Singh and Dr. Soler, analysts will often use a contact stiffness value which is less than the actual value of the stiffness in order to reduce computing time, but yet not so low as to corrupt the solution. Tr. 6041-44 (Singh/Soler). This explanation parallels guidance found in the ANSYS training manual on the use of contact stiffness. PFS Exh. 221; Tr. 9641-45 (Soler).

R255. Thus, for the 2,000-year DBE there was "no incentive" or reason for Holtec to use a lower contact stiffness value because Holtec was able to arrive at a converging solution using a high value for the contact stiffness close to its actual value. Tr. 6042-43 (Soler). With VisualNastran runs, because of the vast amount of data that was being collected, Holtec used a lower contact stiffness in order to decrease the computation time, but it did test runs to ensure that the use of a lower contact stiffness would not "significantly alter" the results. Tr. 6043 (Soler). In this respect, Dr. Soler explained that there is a relatively wide range of contact stiffnesses over which the solution does not show great variation in results. Tr. 6039-41 (Singh). The objective is to select and use a contact stiffness value for the analysis that is within this range. Singh/Soler Dir. at A. 144.

R256. Ignoring Dr. Soler's explanation and the ANSYS guidance, the State claims, quoting Dr. Khan, that a vertical contact stiffness of 454 x 10^6 lbs. per inch makes the vertical frequency of the cask too rigid and underestimates vertical displacement of the cask because "[o]nce [cask] sliding begins, the high [contact] stiffness values artificially treat the solution as linear [e.g., as if the cask is anchored to the pad] without amplifying it in the upward direction and give non-unique or invalid results." State F. ¶ 302, citing Khan/Ostadan Dir. at A28, A31. Although Dr.

Khan never explained what he meant by "artificially treat[ing] the solution as linear," it is apparent from the VisualNastran simulations that the contact stiffnesses used by Holtec neither treat the solution as linear nor effectively treat the casks as if they were anchored to the pad. Out-of-phase motions were clearly evident in the visual simulations and significant lift-off and rotations on the order of 10-12 degrees were shown to occur for the 10,000-year beyond design basis earthquake. PFS Exh. OO; PFS Exh. 86D; Tr. 5775 (Soler). Indeed, in the simulation of the HI-STAR cask that was played during the hearing, Tr. 9769-70 (Soler), the cask tipped over. Thus, the cask stability analyses performed by Holtec clearly do not treat the cask as it were anchored to the pad.[140]

R257. The State further claims, that, absent test data, one <u>must</u> "conservatively capture the dynamic behavior of the cask" by choosing a contact stiffness that correlates with a frequency that falls within the amplified range of the earthquake response spectra curve that provide "the maximum dynamic response." State F. ¶¶ 303-04. According to the State, if the "contact stiffness does not correlate with the frequency in the amplified region of the response spectra, then the mathematical code will treat the problem as linear as if the cask is anchored to the pad." State F. ¶ 303. As stated, the Holtec analysis does not treat the cask as it were anchored to the pad.

R258. "Conservatisms and margins for error in such calculations are necessary and desirable, but must be footed to some extent in reasonable, scientific ground."

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[140] Such a claim is inconsistent with the often-repeated allegation by the State and its witnesses that the analysis takes full credit for the sliding of the cask on the pad and the resulting reduction in seismic loads to the cask. <u>See</u>, <u>e.g.</u>, State F. ¶¶ 148, 183-186; Bartlett/Ostadan Dir. at A5; Tr. 10291 (Ostadan); Tr. 10292 (Bartlett). Indeed, at one point the State would have the Board find: "Nowhere in Holtec's analyses has it presented the forces for the casks analytically anchored to the pad – in the analysis the casks have always been allowed to slide smoothly on the pads. Tr. (Ostadan) at 10291." State F. ¶ 183.

Philadelphia Electric Co. (Limerick Generating Station, Units 1 and 2), ALAB-819, 22 NRC 681, 736-37 (1985); see also Public Service Co. of New Hampshire (Seabrook Station, Units 1 and 2), LBP-76-26, 3 NRC 857, 925 (1976). Dr. Khan's proposed conservatism is not grounded in scientific fact because (1) contact stiffness is a physical parameter that can be calculated, Tr. 9618-24 (Singh), and hence testing is not necessary to determine the appropriate contact stiffness to use for the analysis, and (2) Dr. Khan's methodology would artificially increase the vertical response of the casks – contrary to physical reality – by introducing seismic resonance between the cask and amplified spectral range of the earthquake. Thus, Dr. Khan's results would provide not merely conservative results but answers that bear no semblance to physical reality. See, e.g., Tr. 9633-45 (Singh/Soler).[141]

R259. The State notes that Dr. Khan has opined that a contact stiffness of 1×10^6 to 10×10^6 pounds per inch would correspond to frequencies in the amplified range of the earthquake spectra for the PFSF. State F. ¶ 305. Holtec, however, produced VisualNastran simulations for a range of contact stiffnesses for the 2,000-year DBE, including a contact stiffness that fell within the middle of Dr. Kahn's proposed range, with no significant effect on the results of the analysis. The maximum excursions were still on the order of inches and not feet. See PFS Exh. 85C

[141] In support of its position on the need for conservatism, the State cites a statement by Dr. Singh that "[w]henever a problem cannot be physically modeled [such as with shake table testing], the engineer's only recourse is to make it conservative," Tr. 9685 (Singh), but notes that Dr. Singh disagreed with Dr. Khan's claimed need, absent test data, to choose a contact stiffness that correlates the natural frequency of the cask to the amplified range of the earthquake response spectra. State F. ¶ 306. Dr. Singh disagrees for the reasons stated in the testimony cited above.

and 225. Thus, even using Dr. Khan's unrealistic contact stiffness parameters would not affect the validity of the Holtec cask stability analysis.[142]

R260. The State claims that Holtec "adamantly professes that the dynamic contact stiffness must render a 'realistic' static deflection value." State F. ¶ 308. The State attempts to rebuff that position, claiming that a static deflection computation of contact stiffness would be invalid because the load deflection characteristics of the cask on the pad will change under dynamic earthquake conditions, which could cause the contact stiffness to vary with respect to time. State F. ¶ 309. The State further asserts that there is no contact stiffness when there is separation of the cask and the pad under dynamic conditions, which it claims refutes Holtec's position that the contact stiffness does not change under dynamic conditions. State F. ¶¶ 309, 311. Thus, the State asserts that a static deflection calculation "cannot be used to determine a single unique contact stiffness value for a dynamic analysis where the cask can potentially rock, uplift, and slide." State F. ¶ 310.

R261. Dr. Singh and Dr. Soler make the important distinction that, while the load deflection characteristics of the cask on the pad do change under dynamic conditions, the load deflection characteristic is an output of the cask stability analysis, not an input. Tr. 9628-29, 9639-40, 9645-47 (Soler). In this respect Dr. Soler pointed to

[142] State Finding 307 quotes from an NRC RAI to Sierra Nuclear (that is part of State Exh. 197A) that the response spectrum chosen for the acceleration time history for non-linear analysis must be enveloped by the response spectrum and that the duration of the seismic event must be consistent with high acceleration levels which are associated with strong ground motion durations. The information quoted by the State (the proper characterization of the earthquake and the response spectra) has nothing to do with the appropriate choice of contact stiffness. In any event, none of the background information that would permit assessing the pertinence or significance of the quoted statements is in evidence and the witness himself (Dr. Khan) was unaware of it. He did not even know who Sierra Nuclear was or the cask that was the subject of the RAI. Tr. 9806 (Khan). Thus, State. F. ¶ 307 is not supported by any relevant or credible evidence

classical solutions that use static contact stiffness to solve problems involving dynamic conditions. Tr. 9628-29 (Soler). The Holtec model does account for changes in the load deflection characteristics of the cask on the pad under dynamic earthquake conditions. Tr. 9645-47 (Soler); PFS Exh. 94.

R262. The logic and rationale of Drs. Singh and Soler's explanation are much more compelling than that of Dr. Khan's. Because contact stiffness represents the force at the interface of two bodies that causes a unit of deflection, i.e., causes the bodies to approach or penetrate each other a unit distance, Singh/Soler Dir. at A136, it is apparent that the load-deflection characteristics of the cask on the pad can change under dynamic conditions as argued by the State and as readily acknowledged by Drs. Singh and Soler. For example, if the earthquake causes the cask to lift off the pad, there will be no force acting downward on the pad, and no deflection. These results flow directly from the accepted definition of contact stiffness. However, the fact that the load-deflection characteristics of the cask on the pad change under dynamic conditions does alter the physical properties of the materials that inherently define this contact stiffness. See, e.g., Tr.6048 (Soler). Therefore, absent some non-linearity in the force-deflection relationship, not suggested by the State,[143] dynamic earthquake loadings would not affect the inherent contact stiffness properties exhibited by the two bodies.

R263. The fact that there is no deflection or contact stiffness when the cask lifts off the pad does not demonstrate that the contact stiffness changes under dynamic conditions as argued by the State. Rather, it shows that there is no force acting on the

[143] In this respect, Dr. Singh testified that the contact stiffness of solid bodies is not changed in any significant manner by whether the event is dynamic or static. Tr. 9628 (Singh).

pad and therefore no deflection.[144] In other words, there is a change in the deflection of the cask on the pad, but no change in the contact stiffness, which is the amount of deflection per level of applied force.[145] The contact stiffness parameter represents the spring constant (also expressed in lbs/inch) for the springs at the cask-pad interface. Singh/Soler Dir. at A137, A156. If a cask lifts off the pad, the springs in the model would exhibit no compression, but the spring constant for the springs between the cask and the pad would have not changed. See Tr. 6048 (Soler).

R264. Another example of how the load deflection characteristics of the cask on the pad can change ~~with the contact stiffness changes~~ without the contact stiffness properties changing occurs when the cask lifts off at one end and only a part of the cask is in contact with the pad. Tr. 9646-47 (Soler); PFS Exh. 94. Assuming for purposes of example that the force acting in the vertical direction is unchanged (i.e., only horizontal earthquake forces are acting on the cask), the total weight of the cask is now acting on a smaller area of the pad and, based on the same inherent contact stiffness properties of the pad-cask interface, will cause a greater deflection of the pad in this smaller area.[146]

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[144] The State relies on testimony by Dr. Soler that spoke to there being no contact stiffness when the cask separates from the pad, Tr. 6053 (Soler), which is correct the sense that there would be no compression of the contact spring between the cask and the pad. However, the basic properties of the material, or the potential for compression that represents the spring constant, would not change. Tr. 6048 (Soler) ("contact stiffness is . . . the potential for compression only contact between two surfaces").

[145] By the same token this fact does not contradict Dr. Singh's testimony that contact stiffness does not change in any significant respect whether the event is dynamic or static, as claimed by the State. See State F. ¶ 311.

[146] For example, the Holtec DYNAMO model uses 36 springs between the cask and the pad and the total contact stiffness of 454×10^6 lbs. per inch between the cask and the pad is divided among these 36 springs to provide a spring constant of 12.6×10^6 lbs. per inch for each of the 36 springs. Singh/Soler Dir. at A156. Thus, assuming all of the weight of the cask were acting on the area equivalent to one spring, the compression of that spring, representing the deflection of the pad in that smaller area, would be 36 times that compared to when the weight of

R265. Thus, the spring constants for the springs at the cask pad interface would not change under earthquake conditions. "The only thing that changes is the number of points that may be in contact at a particular instant in time and the vertical force that happens to be acting on the cask at that particular time." Tr. 9646-47 (Soler); PFS Exh. 94. From this changing dynamic input one could calculate the dynamic load deflection characteristics of the cask on the pad, but this is an output of the solution, not an input. Id. Thus, the State is confusing the actual deflection that may occur at the cask pad interface with the contact stiffness that determines the amount of deflection that will occur for a given force.

R266. Thus, in claiming that Holtec mistakenly and "adamantly professes that the dynamic contact stiffness must render a 'realistic' static deflection value," State F. ¶ 308, the State miscomprehends Holtec's criticism as well as the inherent physical nature of contact stiffness. Dr. Singh and Dr. Soler do not claim that the static deflection of the cask on the pad represents the load deflection characteristic of the cask on the pad under dynamic conditions as suggested by the State. Rather, the point that they emphatically stress is that the same contact stiffness chosen for analysis should be able to predict realistic answers under both dynamic and static conditions. See, e.g., Singh/Soler Dir. at A143, A155; Tr. 6049 (Soler). As we already stated, it is undisputed that contact stiffness is an inherent property of the materials, and there is no reason for this inherent physical property of the material to change under dynamic conditions. Accordingly, it logically follows that the same value of contact stiffness should provide realistic answers under both dynamic and static conditions.

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the cask is evenly distributed among the 36 springs. See also Tr. 9646-47 (Soler); PFS Exh. 94.

R267. In this respect, the State and Dr. Khan acknowledge that ⅜ of an inch deflection that would occur under static conditions using a contact stiffness of 1×10^6 is unrealistic. State F. ¶ 313. Therefore, a contact stiffness of 1×10^6 lbs./inch is not a realistic value of contact stiffness and should not be used.

R268. Citing Dr. Soler's testimony on transcript page 6049, the State claims that, "[a]bsent test data, both Dr. Khan and Dr. Soler agree that there is no single correct contact stiffness value that is appropriate for the nonlinear analyses of the cask." State F. ¶ 312. Attributing such an assertion to Dr. Soler grossly mischaracterizes his testimony. While Dr. Soler stated there that "no one number is necessarily correct" for use in numerical modeling, this statement was made in the context that the selected contact stiffness "should be able to analyze equally well . . . the dead load static deflection" on the pad as well as dynamic motion. Tr. 6048-50 (Soler).[147] As discussed above, Dr. Soler testified that there is a range of contact stiffness values that can give reasonable answers and one may choose within this range a lower contact stiffness in order to reduce computation time. Dr. Soler's testimony therefore had nothing to do with the presence or absence of testing, nor with any belief that there is more than one theoretically correct contact stiffness value.

R269. The State also tries to discount the ANSYS guidance on selecting an appropriate contact stiffness, which is consistent with Dr. Soler's testimony on the selection of an appropriate contact stiffness. State F. ¶¶ 315-16. The State first suggests

[147] Dr. Soler was asked a question on what contact stiffness he would expect if the cask rocking frequency were between 2 and 5 hertz. Dr. Soler answered that he would not choose a contact stiffness on the basis of the global motion of the cask. He went on to say that "[I]f you choose a contact stiffness, it should not be problem dependent." Tr. 6048-49 (Soler). Such an explanation cannot reasonably be construed as an admission that there is no single correct contact stiffness value.

that, because ANSYS does not provide sample verification problems for dynamic earthquake conditions, it is unclear whether the guidance can be applied to earthquake "uplifting, rocking, and sliding simulations." State F. ¶ 316. However, as acknowledged by Dr. Khan, ANSYS is a general purpose program. The fact that no examples involving cask uplifting, rocking and sliding are provided does not mean the guidance would not apply to such conditions, and the State points to no reason why the ANSYS guidance – written in broad, general terms (PFS Exh. SS) – would not be applicable.

R270. The State also claims that the ANSYS guidance "does not nullify Dr. Khan's contact stiffness value of 1 x 10^6" because ANSYS advises that finding a "good" stiffness value usually requires "some experimentation," which the State claims is similar to evaluating a range of stiffness values as done by Dr. Khan. State F. ¶ 316. This reading of the ANSYS guidance is inconsistent with the plain language which expressly states that "[m]inimum penetration gives best accuracy." PFS Exh. SS at 3-3. Thus, the purpose of the experimentation recommended by ANSYS is not to determine a contact stiffness that will provide the best accuracy, as claimed by the State, but to identify a contact stiffness value that allows convergence to a solution within a reasonable number of iterations while still providing an acceptable answer. Id. at. 3-14. There is no suggestion in the ANSYS guidance that if one has satisfactorily achieved convergence with a high contact stiffness value, that experimentation would be required to evaluate lower contact stiffnesses as claimed by the State here.

R271. The State also refers to Holtec's Beyond Design Basis Report (PFS Exh. 86C) where for nine of the simulations Holtec "tuned" the soil stiffness so that the mass of the cask(s) and pad resonates at 5 hertz. State F. ¶¶ 323-25.[148] The State claims that "tuning" the soil stiffness to 5 hertz is "a comparable approach to evaluating the cask response at rocking frequencies," but complains that Holtec failed to evaluate higher or lower frequencies than 5 hertz where the dynamic response of the cask may be higher. State F. ¶ 324. As support, the State points to State Exh. 195 which purports to show that accelerations at 5 hertz are exceeded at frequencies above and below 5 hertz. State F. ¶¶ 324-25. On this basis, the State requests the Board to find that "the Holtec simulations with 'tuned' soil stiffness at 5 hertz do not reasonably show that all potential cask rocking and uplift are encompassed in the analyses," and that the "simulations . . . do not validate Holtec's contact stiffness of 464 x 10^6 pounds per inch in the Holtec 2,000-year report or 18.8 x 10^6 pounds per inch in Holtec 10,000-year analyses." State F. ¶ 325.

R272. The State misunderstands the purpose of Holtec's simulations. The purpose of tuning the soil springs under the pad was to explore the claims in Section D.1.e of Contention L/QQ and in the testimony of Dr. Ostadan that Holtec may not have used soil parameters that correspond to the fundamental frequency of the pad.[149] The Holtec simulations sought to address this claim by Dr. Ostadan by tuning the soil springs to the fundamental frequency of the cask/pad system's response to earthquake motions, 5 Hz. Youngs/Tseng Dir. at A44-45; Singh/Soler Dir. at A82.

[148] State F. ¶¶ 318-322 inexplicably digress into a discussion of Dr. Khan's model and Holtec's assertion that it exceeds the accuracy limits of SAP2000, the computer code used by Dr. Khan. This subject is addressed below.

[149] The State, however, does not address this claim in its proposed findings and has thereby abandoned it.

R273. Thus, while Holtec's tuning of the soil springs used the same mathematical formula to select the frequency of the soil spring as Dr. Khan would use for the tuning of the springs between the cask and the pads,[150] the tuning of the soil springs in Holtec's simulations does not relate to the issue of the appropriate choice of contact stiffness. Thus, the State's attack on the validity of the Holtec simulation is irrelevant.[151]

R274. In its proposed concluding findings on contact stiffness, the State would have the Board find that "the evidence is severely wanting with respect to the key dispute between the parties – whether a static contact stiffness is appropriate in a nonlinear dynamic seismic analysis of free standing casks," and that, "in the absence of test data" we should therefore accept "Dr. Khan's design philosophy that to account for potential rocking, uplift, and sliding of the cask, the contact stiffness values must correspond to the amplified region of the response spectra." State F. ¶ 337. The evidence on contact stiffness is not "severely wanting" but rather quite abundant. The record shows that contact stiffness is an inherent physical property of the materials of the contacting bodies that does not change in any significant manner whether the event is dynamic or static. Being a physical property, it is independent of the earthquake excitation and can be ~~compared~~ computed using simple formulae. There is therefore no need to select a contact stiffness that would artificially introduce a seismic resonance condition of the cask and thus produce results that bear no semblance to physical reality.

[150] Compare Singh/Soler Dir. at A117 with Khan/Ostadan Dir. at A31.

[151] With respect to the State's claim that tuning the soil stiffness to five hertz did not evaluate all of the potential soil frequency modes, in its 2,000-year DBE analysis Holtec used three sets of soil springs for the lower bound, best estimate, and upper bound soil properties. Singh/Soler Dir. at A36. The simulations at 5 hertz were in addition to these three base cases. The State does not contest that using the soil springs for the lower bound, best estimate, and upper bound soil properties appropriately captures the range of earthquake frequencies.

b) Choice of Damping Value for Cask Stability Analysis (Responding to State F. ¶¶ 338-353)

R275. The State notes that in the 2,000-year DBE cask stability analysis using DYNAMO, Holtec used an impact damping value of 5 percent and that Holtec believed 40 percent of critical damping to be the appropriate impact damping value for the simulations described in its Beyond Design Basis Report using Visual-Nastran. State F. ¶ 338. The State provides no discussion that finds fault with the 5 percent damping used in the DYNAMO analyses for the 2,000-year return period DBE, yet would have the Board find conclusively that there is "insufficient evidence that impact damping between the HI-STORM 100 cask and the concrete storage pad of 5 percent for a 2,000-year earthquake . . . is reasonable." State F. ¶ 353. Such a proposed conclusion is not supported by the record, or even by the State's own discussion in its proposed findings, hence it must be rejected.

R276. The State devotes considerable discussion (State F. ¶¶ 338-353) to the use of 40 percent critical damping for the Beyond Design Basis analysis.[152] First, the State notes that Dr. Khan expressed "concern that the dynamic response may be underestimated in a nonlinear horizontal sliding analysis" where the friction should be the primary source of energy dissipation, "if energy is also absorbed by using a high damping value." State F. ¶ 340. However, in its model Holtec does not include any dampers that would reduce the effectiveness of the horizontal friction springs. PFS F. ¶ 185. Therefore, as acknowledged by Dr. Khan, friction remains

[152] Although Holtec had intended to use 40 percent of critical damping for the Beyond Design Basis Report simulations, the percent of critical damping used for the simulations was 27.5 percent, which would result in less damping and make the simulations more conservative. Tr. 9671-72 (Soler); PFS Exh 86C at 13 and A-1, A-2; see also Dr. Soler (Tr. 9561-67). Our discussion will focus on the 40 percent critical damping intended.

the energy dissipation mechanism in a situation involving sliding. Tr. 9399-9400 (Khan). [153] Therefore, this criticism is unfounded.

R277. State F. ¶ 341 takes issue with Dr. Singh's testimony that the actual magnitude of the impact damping would be greater than 40 percent based on Holtec having calculated greater than 50 percent impact damping in a simulation of a cask dropped on a very thick concrete foundation. Tr. 6098 (Singh). The State challenges this testimony because PFS neither "proffer[ed] supporting calculations for the impact damping" of greater than 50 percent for a metal cask on a concrete foundation, nor "explain[ed] the details" of the assumptions and relevance "to the impact damping for the HI-STORM 100" referred to by Dr. Singh as support for use of a 40 percent impact damping value. State F. ¶ 341. However, as discussed in Section II above, an expert witness can base an opinion on information and calculations that are not part of the evidentiary record. Moreover, the relevance of the impact damping of a metal cask on a hard concrete surface is obvious. The State was free to cross-examine Dr. Singh on the relevance and assumptions of the calculation to which he had referred, but chose not to do so.[154]

[153] The State also claims that Dr. Ostadan "concurred that the damping has been overestimated which resulted in reducing seismic loads in the dynamic analyses. Tr. (Ostadan) at 10389." State F. ¶ 340. However, Dr. Ostadan was referring to radiation damping by the soil, and not impact damping or other damping associated with the cask, topics on which he provided no testimony. Radiation damping of the soil is a different damping mechanism not pertinent to the energy dissipation due to damping of the cask. See Tr. (6096-97 (Soler).

[154] Dr. Singh also referred to publicly available test data from NRC-sponsored impact experiments that Holtec used to correlate its program and benchmark its calculations. Tr. 9660-61 (Singh). Again, the State would have this testimony ignored because "neither the Applicant nor the Staff offer[ed] any supporting documentation concerning the impact tests, which Holtec program was correlated with NRC data, or how the NRC impact tests relate to damping of HI-STORM casks during a seismic event." State F. ¶ 342. It was the State, however, that failed to pursue the issue on cross-examination, obtain the publicly available test data, or have its experts review the data and comment on them. Having done none of these things, the State cannot blame PFS and the Staff for not entering the materials into the record.

R278. Further, the State takes issue with Dr. Singh's testimony that it was also appropriate to use 40 percent damping for analyzing the 10,000-year beyond design basis earthquake because the percent critical damping is related to the severity of an earthquake event. State F. ¶ 339. As explained by Dr. Singh, the "extent of damping is directly related to the severity of the event." Although 5 percent had been used in doing the 2,000-year design basis analysis "[w]hen we went to the extremely severe earthquakes then it became [more] meaningful, so we don't have absurd modeling of the problem [w]e changed the damping, impact damping to a more realistic yet conservative value, 40 percent." Tr. 9671 (Singh).

R279. The State requests the Board to ignore this testimony because it claims that there is no evidence beyond Dr. Singh's single statement that impact damping increases with ground motion. State F. ¶ 339. However, Dr. Singh stated that the relationship between percent critical damping and severity of the event is recognized in NRC guidance for structural damping. Tr. 9670-71 (Singh). He is correct. In this respect we note that Regulatory Guide 1.61 concerning structural damping does allow a greater percent critical damping for a safe shutdown ~~earthquakes~~ earthquake than for an operating basis ~~earthquakes and~~ earthquake because energy dissipation during an earthquake depends upon "a number of factors" including the design, material used, and "magnitude of the deformations experienced." While not impact damping, the State has provided no evidence whatsoever to suggest that Dr. Singh is incorrect.

R280. The State also generally takes issue with a Holtec animation of three dropping spheres at 1, 5 and 40 percent critical damping. State F. ¶¶ 343-344, 351. The State refers to Dr. Khan's testimony in which he disagreed that "a dropped sphere would be similar to the impact damping between the cask and a pad because the earthquake motion is moving the cask up and down. Tr. (Khan) at 9400-01." State F. ¶ 351. However, in the cited testimony, Dr. Khan did not disagree that there would be impact damping for a sphere dropping on a hard surface, but because he believed that in addition to impact damping other damping mechanisms would also operate under earthquake conditions (such as structural damping and rattling of the casks internals). Tr. 9400-01 (Khan). When asked to consider only impact damping, Dr. Khan did not disagree that the impact damping of a dropping sphere would be analogous to the impact damping of a cask hitting the pad under earthquake conditions. Tr. 9402-03 (Khan).

R281. The State also claims that the dropping sphere analogy is inappropriate because a cask would not simply bounce up and down but would lift up and rock from side to side. State F. ¶ 351.[155] As discussed above, Dr. Khan did not suggest any such distinction when asked about this during the cross-examination.[156] Moreover, the dropping sphere analogy is simply intended to demonstrate the effect of the choice of impact damping on the behavior of the dropped object (sphere or cask). Tr. 9910 (Soler). There is no physical distinction between an earthquake rocking

[155] In this regard, the State refers to testimony by Dr. Soler that the casks would not simply move up and down in an earthquake event, but would also move from side to side. Id. However, the State can point to no testimony by Dr. Soler that the analogy between dropping spheres and uplifting casks was inappropriate. Nor did he testify that sideways motions of the cask would affect in any respect the appropriate percentage of impact damping to use for a cask stability analysis. Tr. 9931-33 (Soler).

[156] After observing the dropping sphere animation during Dr. Singh and Dr. Soler's rebuttal, Dr. Khan in surrebuttal claimed that the impact damping of a cask on the pad during an earthquake event "has nothing to do with the vertical bouncing of an object on a rigid surface." Tr. 9796-97 (Khan); see also id. at 9803-05 (Khan). He claimed that either the energy would be absorbed by distortion during the collision process or for low velocity, short duration impacts the effect of damping would be minimum. Id. However, as explained by Dr. Soler any energy absorbed by elastic deformation of the bodies would be given back as soon as the process was reversed. Tr. 9908-09 (Soler); see also Singh/Soler Dir. at A161.

a cask "up and down" and a ball bouncing up and down due to the effect of gravity in terms of loss of energy from the cask or the ball impacting the surface. Id.

R282. The State also argues that no evidence was proffered that the ball or cask with 40 percent impact damping would "better simulate" cask impact damping under seismic ground motion than the other balls or casks with 5 percent and 10 percent damping. State F. ¶ 352. However, Dr. Soler testified that, "[o]n the basis of [his] experience, he "would expect [a cask] to bounce maybe two, or three or maybe four" times, and thus "in [his] view, a choice of a number around 40 percent of critical damping is correct." Tr. 9911 (Soler); see also Tr. 9661-68; 9931 (Soler); PFS Exh. 225 at 24.[157] Thus, evidence was proffered, by a witness with extensive background and experience, as to which of the animations' damping ratios best represents the impact damping of the steel and concrete storage casks on the concrete pad.

R283. Finally, the State claims that it would be inappropriate to use a value of 40 percent critical damping because the response spectra curve developed by Dr. Khan for "40 percent damping shows relatively no amplification which means the analysis treats the cask as a rigid or anchored system." State F. ¶ 346. Therefore, the State argues "that at 40 percent damping the cask would not uplift and behave as if anchored to the pad." State F. ¶ 347. That is, however, not the case. The results of Holtec's 10,000-year beyond design basis earthquake, as shown on the simulations, clearly shows the casks uplifting and rocking. See PFS Exh. OO. There is no way they would do this if the damping caused them to behave as if anchored to the pad.

[157] In this respect, Dr. Soler also described the 5 percent damping used for the 2,000-year DBE evaluation as "a very conservative representation" of the impact damping at the cask-pad interface. Tr. 6096-97 (Soler).

R284. Moreover, the response spectra curves shown on State Exh. 195 were developed by Dr. Khan using a linear, single degree of freedom system. Tr. 9518-19, 9535-36 (Khan). As Dr. Khan acknowledged, the curves were not generated using a cask on a pad. Id. at 9537-38. They say "nothing," therefore, about the appropriate value of damping that should be used for analyzing the freestanding cask on top of a concrete pad. Tr. 9525-26 (Khan). Thus, State Exh. 195 provides no information as to which damping ratio would best represent the impact damping of the casks hitting the pad during a seismic event, and provides no basis for rejecting the use of a 40 percent damping value.

c) Holtec Sensitivity Analyses (Responding to State F. ¶¶ 330-34, 345-50)

R285. The State takes issue with the "animations" that Holtec performed to test the sensitivity of its cask stability analyses to changes in contact stiffness and damping. State F. ¶¶ 330-34, 345-50. The State references two of the analyses, one using approximately a 40 million pound per inch contact stiffness and 40 percent damping for the 2,000-year earthquake, and another using approximately a 5 million pound per inch contact stiffness and 40 percent damping for the 2,000-year earthquake. State F. ¶ 330; see also State F. ¶ 345. In addition to these two analyses, Holtec also analyzed the cask's stability for the 2,000-year earthquake using approximately a 40 million pound per inch contact stiffness and 5 percent damping. PFS Exh. 225 at 29; see also Tr. 9673-77 (Soler). The results of these three analyses are set forth in Holtec's Report, "Additional Cask Analyses for the PFSF." PFS Exh. 225 at 29.

R286. The State takes issue with the sufficiency of the sensitivity analyses conducted by Holtec because the additional Holtec animations "varying either damping or contact stiffness are insufficient to show that the cask behavior is not sensitive at both lower damping and lower contact stiffness, than used in Holtec simulations." State F. ¶¶ 334, 350. Such a conclusion is unwarranted for several reasons. In the first place, as discussed above, the input parameter values for contact stiffness and damping used by Holtec are reasonable and appropriate ones to use for the cask stability analyses. Second, the State cites no evidentiary support for its claim.

R287. Moreover, the Holtec sensitivity study used as its base parameters reasonable values of contact stiffness and damping, i.e., 40 million pound per inch for contact stiffness and 40 percent for damping. PFS Exh. 225 at 29; Tr. 6046. (Singh); 6061-63, 9911 (Soler). The sensitivity analyses performed by Holtec show that a reduction of contact stiffness by a factor of 8 or of damping by a factor of 8 has little impact on the results. PFS Exh. 225 at 29; Tr. 9676 (Soler). While there are slight increases in the cask displacements, these are minimal, still in the order of inches and not feet. Id. Thus, no adverse results are detectable when one departs from the reasonable values used by Holtec in its cask stability analyses.[158]

R288. The State's criticism is also unsupported since, there are analyses on the record in which Holtec reduced both contact stiffness and damping at the same time from the base case of 40 million pound per inch for contact stiffness and 40 percent for damping. Case 1 of the Beyond Design Basis Report based on the 2,000-year earthquake and lower bound soil springs was run using a contact stiffness of 18.8

[158] The largest displacement is seen in cask 5 in the analyses using approximately 40 million pound per inch for contact stiffness and 5 percent damping. PFS Exh. 225 at 29. The result is a 10.5 inch maximum displacement of the top of cask from its initial location at the start of the run and an 18 inch maximum peak to peak displacement at the top of the cask. Using the formula set out on page 14 of PFS Exhibit 86D, this 18 inch maximum peak to peak excursion at the top of the cask translates to a maximum rotation angle of 2.23 degrees, still providing a safety ~~of~~ factor greater than 10 when measured against the center over gravity angle of approximately 29 degrees at which the cask would tip over due to its own moment. Sing/Soler Dir. at A36.

million pound per inch for contact stiffness and 27.5 percent damping (see note ~~*** infra~~ 152 supra), approximately a 50 percent reduction for contact stiffness and a approximately a 30 percent reduction ~~from~~ for damping from the base case. Again, the results show displacements of inches, not feet. PFS Exh. 86D at 13; PFS Exh. OO.

R289. The State also claims that Holtec did not run a simulation at a contact stiffness of 1×10^6 lbs. per inch. State F. ¶ 344. This proposed finding is simply incorrect. Holtec ran a simulation without SSI effects using Dr. Khan's unrealistic 1 million pound per inch value for contact stiffness and 1 percent for damping, a 40-fold reduction in both from the realistic values of the base case. Tr. 9611-15 (Soler). The results show a maximum displacements of 19.3 inches for the casks from the initial location at the start of the run and a maximum peak to peak excursion of 32 inches at the top of the cask, PFS Exh. 225 at 25, which using the formula on page 14 of PFS Exh. 86D translates into a rotation angle of 3.95. These results show that even using totally unrealistic input parameters for contact stiffness and damping the cask remains stable under DBE loadings, and the great sensitivity claimed by the State does not exist.

R290. The State relies mainly on the spectra curves for various values of damping presented in its Exh. 195 to argue that the Holtec sensitivity analyses are insufficient. See State F. ¶¶ 330-34, 345-50. However, as discussed above, even Dr. Khan acknowledges that those curves say "nothing" about the appropriate value of damping or contact stiffness that should be used for analyzing any particular system. Tr. 9525-26. (Khan). Accordingly, these curves do not show that either the 40 percent damping or 40 million pound per inch contact stiffness values are unreasonable as argued throughout the State's proposed findings. Indeed, the contact stiffness of 40 million pound per inch used as the base value in the Holtec

~~stiffness of 40 million pound per inch used as the base value in the Holtec~~ sensitivity analysis is at least an order of magnitude lower than the calculated, actual contact stiffness between the rigid cask and the pad. PFS Exh 226; Tr. 9623-55 (Singh/Soler).[159]

d) Holtec's Critique of Dr. Khan's Model

R291. The State also requests the Board to discount Dr. Soler's critique and simulation of Dr. Khan's model. State F. ¶¶ 318-21, 326-29. Among other arguments, the State claims that Dr. Khan's parametric study runs did not exceed the capabilities of SAP2000, State F. ¶¶ 318-21, that Dr. Soler admitted he was not a SAP2000 user, State F. ¶ 321, that Dr. Soler admitted he did not model the cask system exactly the same as Dr. Khan, State F. ¶ 327, that Dr. Soler admitted, if he had run Dr. Khan's model with SAP2000, he presumably would have obtained the same results, id., and that Dr. Soler only attempted to replicate one of the twenty parametric runs of Dr. Khan's study. State F. ¶ 329.

[159] The State suggests that the natural frequency of the cask on the pad of 111 hertz calculated by Dr. Soler using a contact stiffness of 454 million pounds per inch is improper in view of State Exh. 195 because it "treats the cask as if it were connected to the pad." State F. ¶ 349. However, because a cask is a rigid body, the natural frequency of the cask would be outside the amplified spectral range of the earthquake shown on State exhibit 195. Tr. 9636 (Singh). In arriving at the natural frequency of 111 hertz, Dr. Soler performed the same calculation for a contact stiffness of 454 million pounds per inch that he had performed for Dr. Khan's contact stiffness of 1 million pounds per inch at pages 21-22 of PFS Exhibit 225, using the same formula that Dr. Khan had used for calculating natural frequency. PFS F. ¶ 173. This formula reduces to a form showing natural frequency as a function of static deflection. PFS Exh 225 at 21-22. Using this relationship, Dr. Khan's assumed natural frequency of 5 Hz would produce what he acknowledges is an unrealistic static deflection of 0.36 inches, whereas Holtec's frequency of 111 Hz is based on the realistic static deflection resulting from a contact stiffness of 454 million pounds per inch. Tr. 9634-35 (Soler). Therefore, contrary to the State's implication it is Dr. Khan's proposed natural frequency that is unrealistic, not that of Drs. Singh and Soler. Again, as acknowledged by Dr. Khan, State Exh. 195 says nothing with respect to appropriate, realistic values of damping and contact stiffness to use for an analysis. Tr. 9525-26 (Khan).

R292. The State's arguments fail to withstand scrutiny. First, as Dr. Khan acknowledges, SAP2000 is a small deflection program like DYNAMO. Tr. 7173-74 (Khan). As discussed above, the State would ignore as unreliable the results produced by DYNAMO for the 2,000-year DBE because it was a small deflection program even though those results reflected only small deflections or displacements of a few inches. Yet, the State would give credence to Dr. Khan's results using SAP2000, also a small deflection program, even though it shows large displacements of many feet. We view the State's positions on the use of DYNAMO and SAP2000 as inherently contradictory.

R293. The State claims that the rotational capabilities of SAP2000 were not exceeded because Dr. Khan checked the time histories of his runs to verify that the cask did not experience large rotations. State F. ¶ 321. In fact, Dr. Khan described the casks moving laterally 30 to 40 <u>feet</u> while bouncing up and down vertically one to two feet in the air. Tr. 9348-60 (Khan); PFS Exh. 89. Unlike Holtec, Dr. Khan never showed the Board the simulation or display of bouncing casks that he had viewed (nor provided it to PFS). In any event, as we have already discussed above, we believe that the caution sounded by Dr. Soler against unquestionably accepting results simply because the computer program says it's so, Tr. 9757, 9775, 9927-28 (Soler), is particularly apt concerning the bouncing of casks. Regardless of whether the casks exhibited large rotations while bouncing, Dr. Khan's results are clearly out of touch with reality. This may be due either (or both) to having exceeded the accuracy limits of SAP2000 or to having used incorrect input parameters. Tr. 9925-28, 9951-54 (Soler). Even the State's own witness, Dr. Ostadan, testified that "I don't believe that those numbers are accurate." Tr. 7391 (Ostadan).

R294. The State goes on to criticize certain simulations performed by Holtec using VirtualNastran, which were intended to test, among other things, the appropriateness of Dr. Khan's use of a contact stiffness of 1×10^6 pounds per inch. State F. ¶¶ 326-329. While not criticizing the computer code itself, the State claims that Holtec did not model the cask "exactly the same as Dr. Khan" (although the State admits that Holtec "used the same number of contact elements and locations") and "used a different representation of the cask." State F. ¶ 327. The State, however, provides no explanation why these differences are material or how they affect the results of the simulation.[160]

R295. Accordingly, it is reasonable to look at Holtec's replication of Dr. Khan's model to see the results that one would obtain using the same input parameters used by Dr. Khan. These results show that, even using Dr. Khan's unrealistic input parameters of 1×10^6 lbs. per inch for contact stiffness and 1 percent for impact damping, the maximum displacements of the casks are on the order one to two feet and not the many feet as shown by Dr. Khan's run on SAP2000. PFS

[160] We note that Dr. Khan associated dampers with the horizontal stiffness springs of his model, whereas Holtec associated no dampers with its horizontal springs including when it otherwise replicated Dr. Khan's model. PFS F. ¶¶ 185, 190; see also PFS Exh. 225 at 15-16. Dr. Khan's inclusion of dampers with the horizontal springs would have dissipated energy in his SAP2000 run of his model compared to Holtec's replication, see Tr. 9397-98 (Khan), which therefore would have reduced the motion of Dr. Khan's model compared to Holtec's replication of Dr. Khan's model. Thus, had SAP2000 worked properly, Holtec should have shown greater displacements than those obtained by Dr. Khan using SAP2000.

Exh. 225 at 25.[161] Thus, even using Dr. Khan's wholly unrealistic input parameters, the casks do not bounce and literally fly through the air.[162]

e) Acceptable Angle of Rotation

R296. The State claims that – in order to ensure an adequate margin of safety – the acceptable maximum angle of rotation for a HI-STORM 100 cask should be 8.15 degrees from vertical. State F. ¶ 356. The State argues that PFS has failed to demonstrate that the HI-STORM 100 cask will not exceed such an angle of rotation with a margin of safety. As support for the latter proposition, the State refers to cask stability analyses performed by Holtec for the 10,000-year beyond design basis, which show angles of rotation that exceed 8.15 degrees. State F. ¶¶ 354-59.[163]

[161] The State's claims that Dr. Soler "admitted" that if he ran Dr. Khan's model on SAP2000 he would have obtained the same results as Dr. Khan. State F. ¶ 327. Such an "admission" is irrelevant, for the issue being tested by Dr. Soler was whether Dr. Khan's model exceeded the capabilities of SAP2000, not whether Dr. Khan had properly ran or used SAP2000. Dr. Soler's testimony showed that whoever ran Dr. Khan's model on SAP2000 would get erroneous results because of the inherent limitations of SAP2000.

[162] The State criticizes Dr. Soler for only replicating one of Dr. Khan's 20 computer runs. State F. ¶ 329. However, Dr. Soler's purpose was to determine why Dr. Khan was obtaining such ridiculously large results for some of his computer runs, i.e., was it the consequence of using unrealistic input values or was it also the result of exceeding the small deflection capabilities of SAP2000. Tr. 9925-28, 9951-54 (Soler). Many of Dr. Khan's other computer runs using more realistic parameters show small displacements similar to Holtec's results. Tr. 9952-54 (Soler). Thus, there is no significance in Holtec's replicating only one of Dr. Khan's 20 runs.

[163] In referencing the maximum angle of rotation for various Holtec 10,000-year beyond design basis analyses, the State notes that on page 13 of PFS Exhibit 86D "50 percent of the maximum peak-to-peak excursion is lower than the maximum excursion recorded at the top of the cask" and asserts on that basis that the "rotation angle calculated in Applicant's Exh. 86D may not reflect the maximum angle of rotation that occurred during the simulations." State F. ¶ 357. The State's request is without evidentiary support and is completely unwarranted. The column labeled "Max[imum] Excursion of Top of Cask from Location at Start of Run" (summarily referred to by the State as maximum excursion recorded at the top of the cask) would not be appropriate to use because in the various 10,000-year simulations it is evident that movements of the base of the casks occurred. See PFS Exh. OO. Therefore, it would be inappropriate to use maximum excursion of the top of the cask from the initial location as the basis for calculating the maximum angle of rotation as suggested by the State. Rather, half the

R297. There is no basis for the concept that a beyond-design basis event, such as the 10,000-year earthquake, be used to define the maximum permissible angle of cask rotation. Design-basis standards are set so that there is sufficiently large margin in the design that the subject structure or component will be able to withstand even a beyond-design basis event without failing. Cornell Dir. at A25. Thus, as explained by Dr. Cornell, in evaluating whether a component or structure would fail for a particular beyond design basis event, the proper procedure is to remove design conservatisms and factors of safety and determine at what point failure will realistically occur. Conversely, one can perform a stability calculation for a beyond-design basis event and confirm through its results that the capacity of the design is at least sufficient to withstand such an event; thus gaining increased confidence in the ability to achieve the desire performance goal under DBE conditions. Tr. 12954-56 (Cornell). A cask whose rotation exceeds 8.15 degrees is still quite far from the 29 degrees that could cause a tipover. Singh/Soler Dir. at 36. Therefore, it would be wholly inappropriate to apply an 8.15-degree standard to the 10,000-year beyond design basis earthquake event, as sought by the State, which PFS evaluated to ascertain whether the cask would meet a performance goal 1 x 10^{-4}.

R298. Indeed, the State's two evidentiary sources for the maximum acceptable angle of rotation of 8.15 degrees from vertical relate to the design-basis standard. The State's first basis, a Holtec presentation in which Holtec suggested that the maximum angle of rotation for the HI-STAR 100 cask should be set at 25 percent of

maximum peak to peak excursion is the appropriate basis for calculating this angle as shown on page 14 of PFS Exh. 86D.

the ultimate cask tipover value, State F. ¶ 355, clearly relates to a design basis standard:

> A set of acceptance criteria to ensure stability with a large margin of safety are also proposed for possible adoption by the regulatory authorities.

State Exh. 174, Cover Page (emphasis added). Thus, Holtec was clearly suggesting a design basis ("acceptance criteria . . . for possible adoption by the regulatory authorities") standard for cask tipover that the NRC might adopt for the HI-STAR cask. The State's second basis, concerns testimony from Dr. Soler with respect to a somewhat different but analogous standard for the HI-STORM 100 cask (maximum excursion at the top of the cask should not exceed half the radius). State F. ¶ 356. The hearing testimony of Drs. Singh and Soler shows that this standard for the HI-STORM (apparently applied internally by Holtec for its cask stability analyses for the HI-STORM) is intended to provide a "factor of safety" in its cask stability analyses. Tr. 6033-35 (Singh/Soler).

R299. If any event, even if the Board were to adopt 8.15 degrees from vertical as the maximum acceptable angle of rotation as a design basis standard applicable to the 2,000-year design basis earthquake, PFSF meets that standard. The maximum angle of rotation from the DYNAMO design basis cask stability analysis for the 2,000-year DBE is 1.026 degrees. The maximum angle of rotation that Holtec computed for its various 2,000-year design basis earthquakes using VisualNastran was approximately 2.23 degrees.[164] Likewise, the maximum angle of rotation

[164] This was the maximum angle of rotation for cask 5 for one of the sensitivity studies referred to in State F. ¶ 358. Indeed, even for the wholly unrealistic contact stiffness and damping parameters suggested by Dr. Khan, the maximum angle of rotation (not taking into account SSI effects) was less than 4 degrees as discussed earlier.

computed by Sandia for the 2,000-year design basis earthquake event was 0.40 degrees. Staff Exh. P at 30.

R300. In State F. ¶ 359, the State would disregard Dr. Singh's testimony that the "actual" maximum angle of rotation for the cask would be "much less" due to the "huge conservatisms" built into Holtec's model, claiming instead that any conservatism in the Holtec nonlinear analyses should be disregarded as "unreliable" since the "record is devoid of any evidence quantifying" these conservatism. However, as discussed several times already, the underlying calculations do not need to be in evidence in order for an expert to rely on them. Also, and more on point here, there may often be recognized conservatisms in a calculation that are not easily quantifiable but which exist nonetheless. At least three such conservatisms apply to Holtec cask stability analyses: (1) Holtec did not account for structural damping of the casks or internal rattling and impacts of the fuel basket and fuel that would occur during a seismic event, PFS F. ¶ 184, (2) Holtec used bounding coefficients of 0.2 and 0.8 for its analyses whereas, based on the authoritative sources, the range of coefficient of friction for steel on concrete surface is 0.3 to 0.7, Singh/Soler Dir. at A77; and (3) Holtec used a contact stiffness of 18.8 million pounds per inch for its 10,000-year beyond-design bases analyses, which produces a natural frequency of the cask of 22.6 Hz whereas the actual contact stiffness and natural frequency of the cask would be much higher, Tr. 9623-25, 9634-35 (Singh/Soler).

9. Shake Table Testing

R301. The State proposes a long series of findings in support of its claim that Holtec's cask stability analysis must be validated with shake table testing. State F. ¶¶ 361-76. The premise underlying the State's claimed need for shake table testing is

Dr. Khan's assertion that non-linear cask stability analyses "are highly sensitive to the assumed contact stiffness between the cask and the pad" and that it is "essentially impossible to pick the contact stiffness for a non-linear dynamic analysis." Khan/Ostadan Dir. at A16, A32. Therefore, Dr. Khan claims that a range of contact stiffness must be evaluated and the results validated by shake table testing. Id. at A32, A34.

R302. As discussed above, contact stiffness is an inherent physical property of the materials of the contacting bodies. Because it is a physical property, it can be computed using standard methodologies. Tr. 9623-25 (Singh). The contact stiffness, as well as the damping values, used in Holtec's cask stability analysis are in accord with physical reality and are reasonable and accurate. ~~Sections IV.G.8.~~ See Section IV.F.8, supra. Moreover, the Holtec cask stability analyses show that cask stability is not highly sensitive to the assumed contact stiffness between the cask and the pad. PFS Exh. 225 at 29. Therefore, while shake table may provide some useful additional information, as various witnesses have testified, the premise underlying the State's claim that shake table testing is necessary does not withstand scrutiny.

R303. The State first points to IEEE 344-1987 concerning Seismic Qualification of Class 1E Equipment for nuclear power plants to support for its position on the necessity for shake table testing of the casks. State F. ¶¶ 362-66. That standard relates to Class 1E equipment, i.e., "electrical equipment and systems that are essential to emergency reactor shutdown, containment isolation, reactor core cooling, and containment and reactor heat removal, or are otherwise essential in preventing a significant release of radioactivity to the environment." PFS Exh. 222. The State refers to section 6 of IEEE 344-1987, which states that "[t]he analysis method is not recommended for complex equipment that cannot be modeled to adequately predict its response. Analysis without testing may be acceptable only if structural integrity alone can ensure the design-intended function."

Khan/Ostadan Dir. at A35. The State further refers to Regulatory Guide 1.100, "Seismic Qualification of Electric and Mechanical Equipment for Nuclear Power Plants," which endorses IEEE 344-1987. State F. ¶ 362.

R304. It is evident that the guidance of IEEE 344-1987 on shake table testing is not applicable to the HI-STORM casks. First, a HI-STORM storage cask obviously does not constitute Class 1E equipment. Tr. 9429 (Khan). Further, IEEE 344-1987 is concerned with the "operability" of electrical equipment, such as pumps and motors. Tr. 9433-35 (Khan). Structural integrity may be part the evaluation; for example, the structural integrity of an electrical cabinet and its contents (switches, relays, etc.) under earthquake conditions may need to be evaluated. But the "focus" of the IEEE 344-1987 is on "operability," i.e., maintaining the flow of electric current and the operability of electrical equipment. Id.[165] Such electrical equipment can involve close tolerances such that very small deformations resulting from earthquake stresses can negate their functionality. The IEEE standard mandates testing of such equipment, critical to nuclear power plant operability, "where small tolerances are important." Tr. 9680-81 (Singh); see also Tr. 7137-41, 9433 (Khan); PFS Exh. 88 at 65.[166]

[165] Further, IEEE 344-1987 concerns mounted equipment, not free standing equipment. Tr. 9436-37 (Khan).

[166] The State's proposed findings refer to Dr. Singh's testimony that for "some" electrical and mechanical equipment very small deformations will negate their functionality, State F. ¶ 364, implying that Dr. Singh testified that this consideration did not apply to other equipment subject to the testing recommendations of IEEE 347-1984. However, the State neither notes nor challenges Dr. Singh's further testimony that it is this class of equipment "where small tolerances are important" that the testing recommendations of IEEE 347-1984 are focused. Tr. 9680-81 (Singh). Another point made by Dr. Singh is that the components subject to IEEE 344-387 are not "very large" and therefore can readily be put on a shake table to be tested.

R305. Unlike Class 1E equipment, a dry storage cask system is an entirely passive system. It does not contain active operating systems with close tolerances critical to safety like a nuclear power plant. In this respect, displacements of inches, and indeed feet, can occur with respect to the casks with no impairment of their health and safety function. Thus, the objective of IEEE-344-1987 of assuring the operability of electrical equipment critical to safety with close tolerances is simply inapplicable to storage cask systems. The State points to no provisions in the regulatory guidance for dry cask storage systems, NUREG-1536, that imposes similar testing requirement for dry storage cask systems, and there are none. Tr. 9681 (Singh).

R306. Even assuming that the guidance of IEEE 347-1984 concerning testing, were applicable, it would not mandate shake table tests here. The IEEE standard states that "analysis methods are not recommended for complex equipment that cannot be modeled to adequately predict its response." In other words, testing is only required where the equipment cannot be modeled to adequately predict its response. <u>See</u> Tr. 9445-46 (Khan). The record here shows that casks can be adequately modeled to predict their response, and in fact they have been so modeled. Two different and independent methodologies have been used to show only inches of cask displacement for the 2,000-year DBE and significant margins against tipover even at the 10,000-year beyond design basis earthquake. State Exh. 173; PFS Exh. 86C; Staff Exh. P.

<u>Id.</u>; <u>see also</u> Tr. 7137-41 (Khan). The State claims that given Dr. Luk's testimony on the availability of a large shake table facility that can accommodate a full-scale cask, Dr. Singh's reference to "the size of components no longer has merit." State F. ¶ 364. We disagree. The record reflects the difficulty of modeling the cask and storage pad system for shake table tests because of their size, and the impossibility of including the soil conditions of the PFS site, <u>see, e.g.</u>, Tr. 7982-83 (Cornell); Tr. ~~***~~ (Ostadan), which the State claims are important in considering the stability of the casks, in any such shake table testing.

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R307. The IEEE standard quoted above further states that "analysis without testing may be acceptable only if structural integrity alone can ensure the design intended function." The State argues that this provision is not applicable here because (1) a cask designer cannot rely on its judgment that its design is adequate, and (2) the Holtec cask stability analysis cannot be used to ensure structural integrity of the casks absent testing, State F. ¶¶ 363, 365.

R308. Holtec has calculated that even in the event of a cask tipover, the deceleration experienced by the spent fuel inside the canister would remain below the design basis deceleration of 45g. Singh/Soler Dir. at A43-A47. The analytical computer program used for this calculation has been verified and validated by actual test data obtained from NRC sponsored tests. State Exh. 197B; see also Tr. 9660-61 (Singh). Further, the multi-purpose canister has large beyond-design basis margins against failure and can withstand deceleration levels far in excess of those predicted by the tipover analysis. Holtec has demonstrated that an unprotected, loaded canister dropped 25 feet onto a hard unyielding concrete surface would only reach 41 percent of the material's failure strain limit. Singh/Soler Dir. at A23, A44.[167] The State has alleged no deficiencies in this analysis undertaken by Holtec.

R309. Thus, the determination that the structural integrity of the cask and canister is sufficient to protect against the release of radioactivity does not rest on unsupported engineering judgment. State F. ¶ 363. Holtec has analytically demonstrated the existence of such protection in accordance with NRC regulatory requirements, designed to assure the public health and safety even in the event of cask tipover.

[167] As discussed in other contexts above, the absence of the underlying calculation does not bar PFS's or this Board's reliance on the results of this calculation.

R310. The State nonetheless suggests that PFS cannot rely upon the Holtec cask tipover analysis here because a cask tipped over by seismic excitation could have an angular velocity greater than the zero velocity that was assumed in the cask tipover analysis. State F. ¶ 365. State's objection is not well taken for several reasons.

R311. First, Holtec's cask tipover analysis was performed in accordance with the NRC's Standard Review Plan ("SRP") for the licensing of ISFIS and was reviewed and approved by the Staff. Staff Exh. C. Because of the conservatisms typically embodied in the NRC SRP design acceptance criteria, a change in one of the input assumptions would not necessarily lead to breach of the stainless steel multi-purpose canister. In this regard, it is well recognized that ductile materials, such as the stainless steel of the multi-purpose canister, have large inherent safety margins beyond allowable code limits against actual material failure. Cornell Reb. at A3; see also Tr. 12814 (Bartlett). The NRC Staff is fully confident that no release of radioactivity will occur even in the unlikely event an earthquake were to result in cask tipover at the PFSF. Tr. 7062-63 (Guttmann); see also Waters Dir. at A15.

R312. Second, as stated, Holtec has analytically demonstrated the inherent conservatisms in the NRC SRP cask tipover acceptance criteria by showing that an unprotected loaded canister dropped 25 feet onto a hard unyielding concrete surface would only reach 41 percent of the material's failure strain limit. Singh/Soler Dir. at A23. This is a much more severe event than either the cask drop or cask tipover events that result in the 45g design basis deceleration. See Singh/Soler Dir. at A43-A47; Singh/Soler/Redmond Dir. at A59-A60. Indeed, the cask drop (in which the canister is protected by the cask) of approximately one foot results in the 45g design basis deceleration. Id.

R313. In its argument, the State focuses solely on the angular velocity of the cask at the point at which the cask commences tipping over. The important velocity in terms of structural integrity, however, is the velocity with which the cask impacts the surface. Singh/Soler/Redmond Dir. at A39. The Holtec simulations for the 10,000-year return period earthquake show precessionary movement of the casks around the vertical axis during the course of the earthquake event. See PFS Exh OO. As explained by Dr. Soler and Dr. Singh, the existence of this oscillatory or precessionary motion would likely mean that (1) the initial angular velocity at the commencement of tipover would be negligible and (2) the precessionary motion would enable the cask to remain stable even after the center of gravity of the cask went past the point at which tip-over would commence for a stationary cask. As a result, the initial height of the cask's center of gravity at which tipover commences is apt to be much lower, and the distance the cask travels before impacting the surface much less, than that for the static tipover scenario (where tipover begins as soon as the center of gravity crosses the vertical plane containing the axis of overturning rotation). Thus, the shorter distance the cask would fall would likely offset any increase in the initial angular velocity from the tipover condition already studied. Singh/Soler Dir. at A170; Singh/Soler/Redmond Dir. at A39. [168]

[168] The State refers to testimony by Dr. Bartlett and Dr. Cornell that the initial angular velocity could be something greater than zero, State F. ¶ 365, but this does not contradict Holtec's assumption as discussed above. Moreover, Dr. Bartlett admitted that he had not been involved in any calculations of cask stability or the results of a tipover event (Tr. 12870 (Bartlett)), and there is no evidence that he has expertise to perform such an analysis. Additionally, Dr. Bartlett professed to have no experience or expertise on the structural integrity of the casks and canisters in the event of a cask tipover. Tr. 12787 (Bartlett). The State mischaracterizes Dr. Cornell's testimony. Dr. Cornell did not agree with State counsel's assertion that, but rather stated: That's an interesting question physically, actually. The initial velocity would probably clearly have to be something greater than zero or it would not be moving in that direction, that is tipping over. But it might, in fact, start at that velocity at a different angle than was presumed in this analysis. Tr. 7978 (Cornell). In other words, Dr. Cornell, without further analy-

R314. The State has proffered no evidence to suggest that a canister would be breached by an earthquake induced cask tipover. The State's witness, Dr. Resnikoff, claimed that the increased angular velocity upon the cask's commencement of tipover initiated by seismic excitation would increase the flattening of the cask and canister, but he advanced no claim – nor even hinted at the possibility – of a canister breach resulting from this increased angular velocity. PFS F. ¶ 534. Thus, the clear weight of the evidence establishes that the structural integrity of the canister would be maintained in the event of an earthquake induced cask tipover, and no release of radioactive materials would occur.

R315. In addition to its reliance on IEEE 344-1987, the State also points to testimony on the record from Dr. Luk concerning the "useful[ness]" of shake table testing. See, e.g., State F. ¶ 367. The State, however, neglects to cite Dr. Luk's extensive discussion on the limitations of shake table testing for cask stability analysis.[169] The question here, however, is not whether shake table testing may be useful from a scientific point of view, but whether it is necessary to establish reasonable assurance of adequate public health and safety. It is not.

R316. Dr. Cornell, who has extensive knowledge of nonlinear seismic analysis, testified that one "would gain information" from shake table testing that would reduce the

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sis could not say that the initial angular velocity would be greater than zero and specifically indicated that it may start at that velocity at a different angle.

[169] Dr. Luk pointed to limitations on shake table testing other than size of a facility, such as only being able to apply one horizontal motion. Tr. 6966-68 (Luk). More importantly, he noted that there are some limitations that cannot be technically overcome. For example, you cannot recreate in situ soil conditions on a shake table test and you cannot incorporate soil structure interaction effects as a result. Tr. 6968 (Luk). Moreover, Dr. Luk never agreed with the State's implicit assumption that shake table testing is necessary to confirm whether a finite model is appropriately constructed. Indeed, in a complicated model like Dr. Luk's that takes into account soil structure interaction, the shake table testing cannot, according to Dr. Luk, simulate that soil structure interaction.

amount of uncertainty, but he went on to say that: "In practice, it's seldom necessary to do so, seldom believed to be necessary to do so when doing nonlinear dynamic analyses of a facility." Tr. 7979 (Cornell); see also Tr. 7975 (Cornell). He further stated that in his opinion that "in this case there is sufficient margin enough to demonstrate that this ten to the minus four accident failure probability is easily reached without the need" for shake table tests. Tr. 8024 (Cornell).

R317. Dr. Cornell further made the important point that "[a] shake table is another model" with its own uncertainties. While one would gain some information, the test would introduce a different set of uncertainties. Tr. 8023-25 (Cornell). For example, it was widely recognized by all witnesses that it would be impossible to duplicate the PFS site conditions in a shake table test. See, e.g., Tr. 7982-83 (Cornell); Tr. 9728-29 (Singh).

R318. Dr. Singh emphasized the difficulty in "simulating the conditions of a cask on the pad" in a shake table test. He explained, for example, why it would be not be feasible to experimentally control the coefficient of friction between the cask and the pad so as to be able to obtain meaningful data that one could correlate with the numerical computer models of free standing casks on a concrete pad. Tr. 9682-84, 9888-91 (Singh). In other words, one would not be able to design a shake table test "to measure all the critical variables that participate in the dynamic behavior" of the cask and then set the input parameters of your computer model accordingly to see how well the results predicted by the program correlate with the test data. Id. at 9890-91. Absent such correlation, one could not use the data from a shake table test as a reliable benchmark for the numerical program. Further, the Japanese had abandoned their shake table testing program for dry storage casks because of difficulties in correlating the test data to the numerical model. Id.; see also Tr. 9740 (Singh).

R319. The State argues that Dr. Singh's views on the usefulness of shake table testing are in "sharp contrast" to those of the other experts, and that because of Holtec's financial interests in the outcome of this case his testimony on shake table testing is "unreliable." State F. ¶¶ 370, 375. It is the rigor and logic of an expert's opinion that determines the weight that is to be given to the testimony, not rhetorical claims of bias. In this respect, Dr. Singh articulated a rational, factual basis for his opinion on the lack of usefulness of shake table testing for free standing casks and was able to provide strong support for his opinion based on the experience of the Japanese shake table testing program. Further, Dr. Singh brings to bear the perspective and experience of someone who both has designed freestanding storage casks and has devised shake table tests and other experiments to confirm and validate the behavior of structures and components. Tr. 9730-31 (Singh). None of the other witnesses spoke to some level of detail about shake table testing as did Dr. Singh. He was the only witness to talk about and focus on specific practical difficulties in devising a shake table test for freestanding casks. Thus, Dr. Singh's opinion on the usefulness of shake table testing was particularly relevant, reliable and well-founded.

R320. Dr. Singh also articulated persuasive reasons why shake table testing is not necessary here. Tr. 9682, 9892-96 (Singh). The State quotes with skepticism Dr. Singh's testimony that shake table testing is not necessary, but fails to refute it. State F. ¶ 370. As Dr. Singh points out, the stability and movement of the casks is based on Newton's fundamental equations of motion that are routinely applied and well understood. The DYNAMO code incorporates these well-understood laws of motion and, as discussed above, has been validated against actual known solutions. Further, the movement and stability of dry storage casks does not involve the precision required of many analyses for which testing is undertaken, nor are there the tight tolerances required of operating electrical equipment for which shake table testing may be appropriate. Tr. 9893-96 (Singh).[170] Dr. Singh's testimony that shake table testing is not necessary is confirmed by Dr. Cornell. Tr. 7979 (Cornell).[171]

R321. Finally, the State claims that "[i]n almost stark contrast to their views with respect to shake table tests or 'experimental tests,' Drs. Singh and Soler testified that '[t]o properly validate a friction model for a free standing structure, it is necessary to check the model you propose against a known analytical solution or against 'experimental results' to demonstrate the code can produce well known problems." State F. ¶ 374 (quoting Singh/Soler Dir. at A132) (emphasis added). Contrary to the State's claim, there is no inconsistency. The testimony referred to by the State clearly refers to validating models against classical solutions or testing as alternative choices for accomplishing the same objective. As discussed above, Holtec

[170] Dr. Singh further testified the casks are conservatively modeled, for example, by not accounting for much of the damping of seismic forces that would occur during an earthquake event due to factors such as the internal impacts of the fuel and basket of the canister. Id.

[171] The State tries to discredit Dr. Singh's testimony on shake table testing with a letter that Dr. Singh wrote in 1997 requesting funding from PFS to conduct such testing. State F. ¶¶ 370-73. However, as Dr. Singh explained (1) the request arose out of the licensing posture at the time concerning Holtec's request for a general certificate of compliance for HI-STORM-100, and (2) the knowledge and understanding of the limitations of shake table tests for freestanding casks has evolved since then. Tr. 9738-48; 9886-88 (Singh). At the time of these communications, the NRC had not yet approved the use of dynamic modeling of cask stability for high seismicity areas, and the Japanese were undertaking shake table tests which were thought at the time might provide useful data. Id. In fact, the Japanese tests did not provide any meaningful test data and the Japanese shake testing program has since been abandoned. Also, since 1997 the NRC has done significant additional work with respect to the dynamic analysis of cask stability, and has commissioned the cask drop tests. Tr. 9740; 9889-92 (Singh).

validated its model against known analytical solutions. Thus, the inconsistency claimed by the State simply does not exist.

R322. As stated above, the issue here is not whether shake table testing is useful or even desirable. Rather, the issue is whether shake table to validate the Holtec cask stability results for the PFSF is necessary to provide reasonable assurance of the public health and safety. It is not, for the following reasons: (1) the cask stability analysis is based on fundamental equations of motion are that are routinely applied and well understood; (2) Holtec used a model that has been validated in accordance with NRC quality assurance requirements to show that it provides reliable results; (3) this model has been used to support numerous NRC licensing actions; (4) contrary to the State's claims, the input parameters for the model are based on well understood and documented principles and are in accordance with physical reality; (5) contrary to State's claim, the results of the analysis are not highly sensitive to the choice of input parameters; (6) the stability and movement of the casks are not subject to close tolerances for which shake table testing may be appropriate. (7) shake table testing is seldom deemed to be necessary to validate nonlinear dynamic analysis of structures and facilities; (8) two wholly different numerical models developed independently by two different technical teams show displacements of only a few inches for the 2,000-DBE and no tipover, with significant margins, for the 10,000-year beyond design basis earthquake.

10. Sandia Report

a) Introduction

R323. The State attempts to discredit the results of the NRC-commissioned Sandia report (Staff Exh. P), which confirms that the HI-STORM 100 storage casks at the PFSF will not overturn or undergo excessive sliding during a 2,000-year or

10,000-year return period earthquake. State F. ¶¶377- 445.[172] The State would have the Board discount this independent confirmation of Holtec's analysis by (1) impeaching the entire NRC cask stability analysis project as suffering from a conflict of interest; (2) attacking the qualifications of Sandia's principal investigator, Dr. Luk; (3) claiming that the Sandia analysis does not accurately take into account the conditions at the PFSF, and (4) asserting that the Sandia results do not confirm Holtec's because the two sets of analyses predict slightly different results for cask rotation and displacement, especially for the 10,000-year beyond-design basis return period earthquake. (Sandia's analyses predict lower cask displacements and rotation than Holtec's). These attacks are inaccurate, based on incorrect presumptions by the State, and reflect the State's lack of understanding of the Sandia report.

R324. The State's discussion of the input parameters used by Sandia asserts that Dr. Luk did not independently verify any input values. State F. ¶¶ 381-82. Yet, there is no dispute that the input parameters accurately or conservatively model conditions at the PFSF site, with the possible exception of the Young's modulus used to model the cement-treated soil at the PFSF (further discussed below).

b) Potential Conflict of Interest

R325. The State tries to raise a potential conflict of interest issue in the work performed by Sandia. State F. ¶ 383. The alleged potential conflict relates to a seven-person

[172] The State tries to create the impression that these analyses were provided to it late in the proceeding by referencing Revision 1 of the Sandia report, dated March 31, 2002. State F. 380 & n.57. In fact, the State had received a copy of Revision 0 of the report on March 8, 2002. The only difference between Revisions 1 and Revision 0 was the addition of two analyses, reflected in Tables 9 and 10. Nothing else in the report differed between the two revisions. Tr. 6864-65 (Luk).

review panel (three NRC Staff and four industry representatives) that provided "recommendations concerning the analysis methodology and range of input parameters" used by Sandia in its generic and PFSF-specific analyses.[173] The State claims that because two members of the panel are connected to Southern Company and Southern California Edison, which are among the utilities that comprise PFS, there may be a conflict of interest. Id. The State does not discuss the nature of the potential conflict it sees in this situation, which does not fall within recognized conflict of interest patterns. See, e.g.. 48 C.F.R. §§ 2009.570-1, 2009.570-2, 2009.570-3.[174] Indeed, the record is absolutely bare of any evidence that the utility representatives gave Sandia incorrect (or any) technical advice, or that Sandia followed any such advice, or that any advice provided by the utility representatives adversely affected the validity of the results of Sandia's PFSF analysis. There is nothing, other than the State's speculation, to support the notion that even a potential conflict of interest existed.

R326. Dr. Luk testified that he was unaware of the PFS connection of the two review panel members. Tr. 6995-96 (Luk). However, the State would have the Board "presume that the Staff was aware that representatives from PFS companies were

[173] The PFSF report is one in a series of analyses being conducted by Sandia for the NRC of dry cask storage systems. Other analyses include a generic study and site-specific investigations for the Hatch and San Onofre nuclear power plants. NRC Staff Testimony of Vincent K. Luk and Jack Guttman Concerning Unified Contention Utah L/QQ (Geotechnical Issues) (inserted into the record after Tr. 6760) ("Luk/Guttman Dir.") at A6; Tr. 6763-65, 7023-25 (Luk).

[174] Dr. Luk testified that he understood that the representatives from Southern Company and Southern California Edison became members of the panel because their companies anticipated that Sandia would be performing seismic stability analyses for their respective plants, Hatch and San Onofre, which Sandia ultimately did. Tr. 7081-82 (Luk). By the time the decision was made to perform a site-specific analysis for the PFSF, the composition of the review panel had already been established. Id.

on the advisory panel. Tr. 7053-54; 7081-86." State F. ¶ 384.[175] The State further suggests that these potential "conflicts of interest" should have been disclosed to the State, and that as a result of this non-disclosure the State "had little or no opportunity to probe the backgrounds of the advisory panel and its influence on the Luk methodology and analysis during discovery. Id. This is clearly not so. Dr. Luk was deposed on May 3, 2002 and testified for two days (May 6 and 7, during which time he was subjected to intense examination by counsel and the Board on the activities of the review panel. See Tr. 6970-71, 6993-96, 7052-56, 7071-91, 7102-05, 7128-31 (Luk). Thus, the State's complaint of "lack of opportunity to probe the background of the advisory panel" has a hollow ring.[176]

R327. What was gleaned from the extensive examination of Dr. Luk on the review panel was that the panel gave helpful advice on technical issues such as what damping to use, the values of the coefficient of restitution, and the merits of using a single cask on a single pad for the analyses. Tr. 7084-85 (Luk). At no point did the review panel members provide any advice that Dr. Luk considered inappropriate. Id. This is confirmed by the written minutes of the meetings of the panel, which reveal that the meetings were of a highly technical nature, as would be anticipated for such a panel. See Staff Exh. GG.

R328. Thus, while State attempts to manufacture an apparent "conflict of interest" issue, there is not even a hint of such a conflict in the record. Even if the Board were to

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[175] There is nothing in the testimony cited by the State in State F. 384 to suggest that the Staff was aware of the "potential conflict" alleged by the State.

[176] Dr. Luk returned to testify for a third day on June 19, 2002. The State had been provided with copies of the minutes of the meetings of the review panel during the May hearings. See Staff Exh. GG; Tr. 7128-31. If the State had any remaining issues to explore regarding the role of the review panel arising from these minutes or otherwise, it could have brought those issues up during the June hearings. It did not.

accept the State's invitation (State F. ¶ 384) that the Board "must weigh" such a potential conflict in its assessment of the Sandia report, the weight afforded to the State's alleged conflict of interest should be zero.

R329. Under NRC regulations, the Commission, as a matter of course, evaluates contractors for conflicts of interest. See, e.g., Regulations Implementing the National Environmental Policy Act of 1969, 52 Fed. Reg. 20314 (1987). The applicable regulatory provisions are found under 48 C.F.R. Subpart 2009.5. 48 C.F.R. § 2009.570-2 defines organizational conflict of interest as:

> Organizational conflicts of interest means that a relationship exists whereby a contractor or prospective contractor has present or planned interests related to the work to be performed under an NRC contract which:
>
> (1) May diminish its capacity to give impartial, technically sound, objective assistance and advice, or may otherwise result in a biased work product; or
>
> (2) May result in its being given an unfair competitive advantage.

Neither of these relationships are present between Sandia National Laboratory and the NRC.

R330. NRC regulations provide additional criteria for recognizing when a contractor may have an organizational conflict of interest:

> (a) General. (1) Two questions will be asked in determining whether actual or potential organizational conflicts of interest exist:
>
> (i) Are there conflicting roles which might bias an offeror's or contractor's judgment in relation to its work for the NRC?
>
> (ii) May the offeror or contractor be given an unfair competitive advantage based on the performance of the contract?

48 C.F.R. § 2009.570-3. In the present instance, the answer to both questions is no.

c) **Sandia's Experience**

R331. The State exerts Herculean efforts to discredit the experience of the Sandia team. See State F. ¶¶ 385-404. The battle is lost from the start, however, when the State declares that "Dr. Luk's *sole experience* in modeling the free standing storage casks includes the site specific analysis for PFS, Hatch and San Onofre." State F. ¶ 385, emphasis added. However, Dr. Luk has accumulated huge experience as part of a large team for more than three years.[177]

R332. The State seeks to distinguish Dr. Luk's experience in modeling the seismic response of free standing dry storage casks by citing differences among the sites (e.g., "[t]he Hatch site store [sic] 12 casks on a concrete pad in a 2 x 6 array, however Dr. Luk modeled a square pad with a 2 x 2 array"). Id. This tactic ignores the record and Dr. Luk's actual experience. Dr. Luk has spent over three years of extensive work on free standing cask stability analyses, resulting in "a huge accumulation of experience" in performing non-linear analyses for different dry cask storage systems under various conditions and assumptions. Tr. 6987 (Luk). The State's assertion that "Hatch and San Onofre do not provide relevant modeling experience for the PFS design or site conditions" (State F. ¶ 385), is unsupported by evidence and simply wrong.[178] The only significant difference between

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[177] By contrast, the State's cask stability "expert" Dr. Khan has never performed a cask stability analysis. Tr. 7136, 7141-42 (Khan); PFS Exh. 88 at 67.

[178] For example, while the Hatch plant's design basis earthquake is of less magnitude than PFSF's, Sandia conducted a series of parametric studies at the Hatch plant to generate large motions by the casks. Tr. 6916 (Luk). For the San Onofre plant, Sandia analyzed an earthquake of 1.5g magnitude, comparable to the 10,000 year return period beyond-design basis earthquake for the PFSF. Id.

the cask stability analyses conducted for Hatch and San Onofre and that conducted for the PFSF site is the presences of soil cement at the PFSF site. As discussed below, the soil cement and cement-treated soil layers at the PFSF are properly accounted for in the Sandia model.

R333. The State further tries to dismiss the significance of the analyses contained in the Sandia report by denigrating the expertise of Dr. Luk and other members of the Sandia team. The State asserts that Dr. Luk waffled on his expertise with soil structure interaction. State F. ¶¶ 388-391. However, Dr. Luk correctly pointed out that soil-structure interaction effects need not be taken into account through a separate analysis, but are accommodated by the computer code if the structures and the underlying soil are properly modeled. Tr. 7036-37 (Luk). [179] There is no doubt that Dr. Luk is an expert in the effects of the dynamic coupling between soil and structures. Id. While the State describes the record as "bare" with respect to Dr. Luk's qualifications to model soil structure interaction effects (State F. ¶ 390), Dr. Luk testified as to his extensive recent experience over several years in looking at soil structure interaction issues at nuclear power plants. Tr. 7038 (Luk), and his experience in analyzing soil structure interaction effects goes back to graduate school. Tr. 7036 (Luk). Dr. Luk and his colleagues at Sandia have for years been performing analyses that include soil structure interaction effects. Tr. 7038 (Luk).

R334. The State then seeks to undercut Dr. Luk's experience because he has not previously modeled precisely the same seismic setting. State F. ¶ 392 ("Dr. Luk does not have experience in the nonlinear modeling of the seismic behavior of cylindri-

[179] Dr. Luk clarified that where his expertise was limited was in soil mechanics, and that he depended on another expert (Po Lam) to provide soil characterization input. Tr. 7037 (Luk).

cal free standing casks supported by cement-treated soil and a relatively soft clay foundation at ground motions equal to or greater to [sic] the 2,000-year earthquake at PFS.") Id. As explained in Section II above, the State's attempts to deny a witness' expertise if he has not previously worked on exactly the same physical problem in exactly the same physical setting are contrary to the law and factually untenable.

R335. The State's attempt is particularly noteworthy in this instance, because Dr. Luk has years of training and experience that are without question applicable to his analyses for the PFSF. Moreover, as coordinator of the NRC's generic cask stability analysis and the site-specific analyses for the Hatch and San Onofre plants, he has three years of extensive work *directly applicable* to the issues in this proceeding. Thus, the State's attempts to question Dr. Luk's credentials are not detrimental to Dr. Luk's credibility, but the State's.

R336. The State also claims, with no reference to the record, that there is "insufficient evidence to find that Dr. Luk's associates in his analysis are qualified to accurately model the soil dynamics or the soil structure interaction effects." State F. ¶ 391. This naked assertion is unsupportable. The qualifications of Mr. Dameron and Mr. Lam are established in the record. The record shows that Mr. Dameron is a leading authority in finite element analysis with at least 20 years of experience in the field. Tr. 6765-66 (Luk), and Mr. Lam has over 25 years of experience in seismic analysis. Tr. 6766 (Luk). Dr. Luk testified that his team had all the technical expertise necessary to undertake their analysis of cask stability at the PFSF. Tr. 6767 (Luk). Dr. Luk's testimony on the qualifications of his team members was unchallenged.

d) The Luk Report Does not Confirm Holtec's Analyses

R337. The next section of the State's proposed findings (State F. ¶¶ 394 – 404) is devoted to arguing that the Sandia report's result do not validate those obtained by Holtec because (1) the models and methodology are different and Sandia did not undertake to compare some of the elements in its model with those predicted by PFS, (2) the results of the two analyses are not comparable, (3) Sandia's model is too complex and thus unreliable, and its results have not been verified, and (4) there were shortcomings in Sandia's modeling of site conditions at PFSF. In each instance, the State either misunderstands the nature of the analyses or mischaracterizes the testimony of the witnesses.

R338. With respect to the differences between the two models and methodologies (State F. ¶¶ 394 –395), it is unclear what point the State is trying to make. Nobody has claimed that the Holtec model and methodology are the same, nor is there a claim that Sandia set out to (or in fact did) reproduce Holtec's results. Thus, this allegation is a just a straw man without significance. What is important, however, is that the Sandia model is comprehensive, uses appropriate methods and techniques, and arrives at *results* that essentially agree with Holtec's. Tr. 5899 (Singh).

R339. With respect to the differences in results obtained by the two models, particularly for the 10,000-year beyond-design basis earthquake and a coefficient of friction between cask and pad of 0.8 (State F. ¶ 394), such differences are to be expected. As Dr. Singh testified, "[w]hen you model a complex problem and you take a different modeling path you're going to have some differences in the final results.

But the solutions in the end are essentially in agreement with ours." Tr. 5899 (Singh).[180]

R340. The difference in methodologies between the two analyses is not a basis for questioning either set of results. Indeed, had Sandia used the same methodology and obtained the same results as Holtec, there would be little confirmatory value in the Sandia's results. It is the fact that Holtec and Sandia used two different methodologies what makes the Sandia report's result analyses confirmatory of the Holtec analyses. It is because the Sandia analyses differ in many respects from Holtec's with respect to assumptions or methodological approaches about which the State expressed concern (e.g., choosing a particular contact stiffness value, choosing a particular damping value (Tr. 6812-13 (Luk)), not taking into account the effects of non-vertically propagating seismic waves (Tr. 6789-90 (Luk)), using soil springs to represent soil dynamic behavior (Staff Exh. P at 7), not modeling soil structure interaction fully, etc.), that the analyses are confirmatory, arriving at the same conclusions without using methodological assumptions the State contended were problematic in the Holtec analyses.[181] <u>See,e.g.</u>, Tr. 6827-29 (Guttman)

R341. The State asserts that Dr. Luk failed to compare elements of Sandia's analyses to Holtec's (i.e., the soil structure interaction effects and the deconvoluted time histories for both the 2,000-year and 10,000-year return period earthquakes). State

[180] The State cites Dr. Luk's testimony that his and Holtec's results should not be directly compared due to the different methodologies employed and the different input parameters. State F. 395. Dr. Luk's testimony was only that he would not use a direct comparison method to evaluate the integrity of the two sets of results. Tr. 6952 (Luk). While direct, one-to-one comparisons of individual results may be inappropriate, the Sandia analyses of the PFSF was commissioned to provide independent confirmation of the Staff's determination that the PFS analyses were acceptable. Tr. 6828-29, 6835-37, 6846-47 (Guttman). They provided such confirmation. Tr. 6830 (Guttman).

[181] The State of course developed an entirely new set of concerns over the methodology employed in the Sandia report, as discussed below. Those concerns also have no merit.

F. ¶ 396. However, Dr. Luk testified that Sandia's dynamic analysis for the PFSF was conducted independently of PFS's and in fact he was not even aware that the Holtec analyses had been conducted at the time Sandia performed its evaluation. Tr. 6937-41 (Luk). Since Sandia's work was intended to be an independent evaluation, it is neither surprising nor significant that Dr. Luk had not sought to compare certain elements of his model to PFS's.

R342. The State suggests that because Sandia's model was not benchmarked against "physical data, such as shake table tests," they are not confirmatory of the Holtec analyses. State F. ¶ 397. As discussed in Section IV.F.9 above, the State's arguments on the need for shake table testing are without merit. The State also offers no explanation why the absence of physical benchmarking renders the Sandia report analyses non-confirmatory of the Holtec analyses. The absence of shake table tests does not mean that the adequacy of the Sandia model has not been independently established. The ABAQUS code has been benchmarked against a wide variety of classical problems. PFS F. ¶ 200. For the specific case of the PFSF, Sandia checked the results produced by the analysis against test data to verify the appropriateness of the analytical results. Tr. 6812-13 (Luk) (damping benchmarked against drop test data).

R343. The State seeks to dismiss the sensitivity analysis conducted by Sandia for its seismic analyses of the Hatch plant ISFSI because "the record contains no evidence that the results generated from the Hatch model, in fact, accurately predict the seismic behavior of the cask, storage pad, and foundation." State F. ¶ 400. Again, the State continues to try to apply its newly-minted rule – that all underlying data supporting an expert's opinion must be in the record for the opinion to be given weight. As discussed in Section II above, there is no such a requirement.

Dr. Luk provided convincing testimony as to how Sandia went about conducting analyses at Hatch at increased seismic levels until the casks were predicted to tip over. Tr. 6986-88 (Luk). Dr. Luk's testimony was not challenged by any witness and the State did not cross-examine him on the methodology or results of the Hatch evaluation. Thus, in complaining that no additional evidence has been placed on the record as to the Hatch evaluation, the State is pointing the finger at itself.[182]

R344. The State also argues that the Sandia model cannot be relied upon to confirm Holtec's results because the Sandia model is "very complicated" and "dependent on the input parameter." State F. ¶ 398. In the first place, it is ironic that the State would criticize the Sandia model for its complexity, given that the Sandia model includes a number of features whose absence from Holtec's were categorized by the State as deficiencies in the latter.[183]

In addition, the State's suggestion that the model used by Dr. Luk in his analyses is too complicated trivializes the amount of research, testing, and analysis that has gone into the underlying project. The Sandia project was developed by the NRC to establish criteria and review guidelines in evaluating the seismic behavior of

[182] The State also makes the irrelevant observation that the Hatch parametric study can not be cited as confirmation of the adequacy of the Sandia model because "the PFS model was modified to simulate the soil cement layer at the PFS site." State F. ¶ 399. Whatever Sandia did for the PFSF specific model has no bearing on the fact that the computer modeling technique used in the various analyses conducted by Sandia was validated by the Hatch parametric analyses. In any event, Dr. Luk also testified that Sandia had successfully incorporated the soil cement layer into its PFSF model. Tr. 7028 (Luk). His testimony was not challenged or refuted.

[183] Thus, the Sandia model was able to model large cask deformations (displacements and rotations) and was able to capture the effects of pad flexibility, non-vertically propagating seismic waves, pad-to-pad interaction, pad settlement and soil-structure interaction. See, e.g.,Tr. 6768-70 (large deformations), 6788-89 (pad flexibility), 6790-91 (soil structure interaction), 6820-21 (non-vertically propagating waves),

dry cask storage systems; and in examining the dynamic seismic behavior of free-standing dry cask storage systems and soil-structure interaction effects in simulated earthquake events. Luk/Guttman Dir. at A2(b). That Sandia has developed a large, sophisticated, complex model cannot be cited as a weakness but as a strength, particularly since Sandia has validated the analytical tools it uses in a variety of ways. See Tr. 6767-70, 6817-19, 6955-56, 7003-04 (Luk); .[184]

R345. No testimony was provided by the State that challenges the adequacy of the analytical model used by Sandia.[185] The State therefore resorts once again to taking out of context Dr. Cornell's caution about "not being too enamored with the computer program itself." State F. ¶ 398. As discussed above in connection with State F. ¶ 256~~.~~, ~~T~~this reference to Dr. Cornell's testimony is taken entirely out of out of context in an attempt to make it stand for the opposite of Dr. Cornell's actual testimony. As discussed in Section IV.F.2 above, Dr. Cornell expressed no concern with the computer model analyses conducted by either Holtec or Sandia. To the contrary, he testified that the Holtec and Sandia analyses had served to reduce uncertainty in the estimation of cask performance. Tr. 8022 (Cornell). Indeed, in responding to a question from Judge Lam on whether non-linear analysis is generally suspect or "unreliable," Dr. Cornell's response was emphatic: "Absolutely not. No. Typically they are reliable." Tr. 8010 (Cornell).

R346. With respect to the claim in State F. ¶ 398 that the Sandia analysis is "dependent on the input parameter," Dr. Luk testified that Sandia performed extensive

~~sensitivity analyses to~~ assure itself that it had accommodated the effect of the

[184] Were Sandia's model not complicated, the State would no doubt criticize it as simplistic. See, e.g., State F. ¶ 207.

[185] Dr. Bartlett testified about certain problems he perceived with the modeling of the pad foundations for the PFSF, but restricted his comments to the properties of the materials as listed in the Sandia Report and whether those properties were representative of conditions at the PFSF site; he did not criticize the analytical tools used by Sandia. Tr. 10347 (Bartlett)

tivity analyses to assure itself that it had accommodated the effect of the choice of input parameters on the analytical solutions. Tr. 6772-73, 85-88 (Luk).

R347. Finally, the State alleges a number of specific deficiencies in Sandia's analyses, all relating to alleged insufficiency of data or documentation to support Sandia's conclusions: (1) insufficient confirmation that Model Type 1 simulations – with a single cask moving on the pad – maximize cask displacement (State F. ¶ 402); (2) inadequate documentation to support the Dr. Luk's testimony regarding lack of pad-to-pad interaction effects (State F. ¶ 403); and (3) lack of documentation that the Model Type 1 simulation maximized cask displacement for the 10,000-year return period earthquake (State F. ¶ 404). Again, the State cites to no evidence to support its criticisms. No witness testified as to these defects, so the State falls back on its familiar refrain that there is "no documentation" to support Dr. Luk's testimony. State F. ¶ 402. The State has developed no case rebutting Dr. Luk's testimony through its own witnesses or on cross-examination; thus, it has simply failed to meet its burden of going forward.

R348. In any case, the deficiencies in the Sandia analysis asserted by the State do not exist. For example, the State asserts that there is insufficient data to verify that "modeling a single cask on a pad is adequate because that cask rotations will be larger if the casks [sic] movement is in phase and independent of other casks." State F. ¶ 402. Yet, the uncontroverted evidence is that Dr. Luk conducted a sensitivity study to determine that this was, indeed, correct. Tr. 6774-6781 (Luk).

R349. Even when Dr. Luk's testimony is uncontested, the State argues the opposite. Thus, Dr. Luk testified that the results of the Sandia analyses show that, for the 2,000 year DBE, the seismic response of a single cask on a pad is indifferent to the location of the cask on the pad. Tr. 6956 (Luk). Notwithstanding this unchallenged testimony, the State would have the Board hold that "the cask stability results may be dependent upon the specific location of the cask on the pad" (State F. ¶ 404), without a scintilla of evidence to support that finding.[186] The data show that the casks behave independently of one another and their behavior is not dependent on the location of the casks on the pad. These results are confirmed by Holtec's VisualNastran analyses. See PFS Exh OO.

e) Sandia Report Shows Significant Soil Structure Interaction Effects

R350. The State repeats the discredited argument that Figure 17 of the Sandia report demonstrates a large degree of soil structure interaction leading to increased pad accelerations compared to the free field. State F. ¶ 405. However, as discussed in Section IV.D.4 above, Figure 17 cannot be used to say anything meaningful about the accelerations that the pad will undergo, since it represents raw, undamped data. Tr. 6803-06 (Luk). In fact, Dr. Luk testified that Figure 17 showed the presence of soil-structure interaction effects, but would not accept the characterization that the figure showed the "significance" of those effects. Tr. 6930 (Luk).

f) Modeling PFS Foundation Soils

[186] The State notes that Sandia did not conduct a similar sensitivity analysis for a single cask on a pad under the a beyond-design basis 10,000 year earthquake. State F. ¶ 404. The absence of such an analysis does not support the inference that the State would draw, i.e., that "cask stability results may be dependent upon of the specific location of the cask on the pad."

The State also refers to Holtec's VisualNastran simulation which, in one 10,000 year earthquake simulation, showed that cask # 5 moved significantly more than cask #1. State F. ¶ 404. However, that was a case in which the pad was loaded with eight casks, so it is not germane to Dr. Luk's conclusion that, for a single cask, location on the pad does not affect the results.

R351. The State contends that Dr. Luk's modeling of the foundation soils at the PFS suffers from several defects, including: (1) modeling of the interface between model elements as a frictional interface, not representative of the "actual PFS design or the PFS soils" (State F. ¶¶ 407-08, 412); (2) not reflecting the PFS design intent to rely on cohesion from bonding at the interface layers to transfer horizontal earthquake loads downwards from the pad to the underlying soils (State F. ¶ 414); (3) failing to account for the post-yield behavior of the Upper Lake Bonneville clays (State F. ¶ 412); and (4) using the soil characteristics developed by Geomatrix, Inc. rather than those developed by Stone & Webster (State F. ¶ 415). These contentions about Sandia's modeling of the soil foundation are the result of a profound misunderstanding by the State and its witnesses regarding how the soil foundation was actually modeled.[187]

R352. The first deficiency alleged by the State is that using a coefficient of friction to model the boundary between two sub-elements in the model is incorrect. The State starts by asserting that the Staff *directed* Dr. Luk to use a coefficient of friction of 0.31 at the pad and cement-treated soil interface (State F. ¶ 406), implying that this was an arbitrary directive. The evidence in fact shows that the Sandia team used sensitivity studies, testing various combinations of upper bound and

[187] Dr. Bartlett raised two other concerns about Sandia's modeling of the foundation soils: the assumed thickness of the cement-treated layer and the value of the Young's modulus used in the analysis. See Tr. 11481-82 (Bartlett). The Young's modulus issue is discussed separately below. With respect to the thickness of the cement-treated soil layer, Dr. Bartlett expressed a concern that Sandia's model assumed a uniform thickness of two feet for the cement-treated soil layer, whereas two feet is a maximum value and the actual thickness can be as little as one feet, depending on the amount of aeolian soil that needs to be replaced with a cement-treated soil mixture. Tr. 11445-46 (Bartlett). Dr. Luk explained, however, that while Sandia was aware that the thickness of the cement-treated soil mixture was variable, the decision was made to use the higher value for the thickness of the cement-treated soil because with a thicker layer of cement-treated soil, more of the energy that is associated with the ground excitations will go to the pad and the cask, so in that sense, more conservative results will be generated in evaluating the dynamic behavior of the cask. Tr. 11544 (Luk).

lower bound coefficients of friction at each of the model interfaces, in order to determine which parameters would maximize cask response to either sliding or tipping. Luk/Guttman Dir. A11.[188]

R353. In modeling the interfaces above and below the cement-treated soil, Sandia used a well-established method of finite element modeling. Tr. 11511-12 (Luk). The State and its witness Dr. Bartlett misunderstand Dr. Luk's methodology. It was not, as Dr. Bartlett interpreted it, to treat the underlying Upper Lake Bonneville clays as if they were "sand." State F. ¶ 409; Tr. 10530-35 (Bartlett). In reality, as Dr. Luk testified, modeling the interface using a frictional relationship does not represent characterizing the properties of the materials, but that of the interface between them. Tr. 11510-12, 11573, 11580-81 (Luk). As described by Dr. Luk:

> . . . Coulomb's Law of Friction is a description of the frictional resistance at the interface, as material properties at the interface. It's also a parameter that has depends on the material, but more on the surface condition of the two bodies.

Tr. 11510 (Luk).

R354. The State would have the Board give "particular deference" to Dr. Bartlett on this issue. State F. ¶ 420. However, Dr. Bartlett is admittedly unqualified to render an opinion as to how a finite element model should be constructed or interpreted; he acknowledged that he could not comment on the appropriateness of the modeling techniques used by Dr. Luk and his Sandia colleagues, but was limiting his comments to the properties of the materials analyzed by Sandia. Tr. 10347 (Bartlett). ~~As~~ Dr. Luk testified that the Sandia model did not represent any particular

[188] In the final analyses, the coefficients of friction at the soil cement/soil and the pad/soil cement interfaces were set at 1.0 (upper bound) and 0.31 (lower bound). The coefficients of friction for the cask/pad interface were 0.8 (maximizing cask rotation, i.e., potential for tipping) and 0.2 (maximizing horizontal sliding displacement). Luk/Guttman Dir. at A11.

material at the interface, but rather the "physical phenomenon associated with a sliding resistance, based on Coulomb's Law of Friction." Tr. 11586 (Luk).

R355. The State goes to great lengths to describe the materials at the site and how they do not agree with the coefficients of friction used by Dr. Luk. State F. ¶ 416-426. However, as Dr. Luk testified, the coefficient of friction at the interface does not represent a property of a material. Tr. 11573, 11580-81 (Luk). Thus, the State's attacks fall wide of the mark since they rebut assumptions that have not been made and methodologies that have not been applied in Sandia's analyses. See also PFS F. ¶¶ 212-215.

R356. As part of its erroneous argument, the State argues that the soils at the PFSF are held together by cohesion, and that soil cohesion was not taken into account as a property of the underlying soils by the Sandia model. State F. ¶ 419.[189] These

[189] While the State cites transcript page 6787 for the proposition that "Dr. Luk admitted that his model does not incorporate cohesive strength of the soils," Dr. Luk stated nothing of the sort but clarified that the use of the coefficient of friction at the interface is "purely a kinematic representation of the frictional resistance of one substructure on top of the other." (Tr. 6787 (Luk)). In other words, the coefficient of friction does not model the behavior or properties of the soil, but conditions at the interface between the soil layer and the cement-treated soil layer.

Indeed, the cited question asked by counsel for the State does not even address the issue of internal cohesion of the soils, but what the coefficients of friction represent:

> Q. And both these cases were run for a coefficient of friction between the soil and -- going back to the table, why don't you explain what the Mu 1 and Mu 2 represent.
>
> DR. LUK: Yes. Mu 1 is the coefficient of friction at the interface between the bottom of the cask and the top of the concrete pad. Mu 2 is the coefficient of friction at the interface between the bottom of the concrete pad and the top of the soil cement layer.
>
> Q. And you assume a [Mu 2] in these two cases of 0.31. And what does that represent in terms of the capability of the pad to slide?
>
> DR. LUK: Would you like to qualify the question?
>
> Q. I'll rephrase the question. Does using a [Mu 2] of 0.31, does that incorporate any of the shear strength of the soil in being able to resist sliding?
>
> DR. LUK: When we use Mu as the coefficient of friction at the interface it is purely a kinematic representation of the frictional resistance of one substructure on top of the

State assertions are also incorrect. Dr. Luk testified that the Sandia model did take into account the internal cohesion of the materials modeled (Tr. 11573-75, 11580-81 (Luk)), contrary to the State's assertion.

R357. Moreover, if there was error in Sandia's model and it indeed treated the soils as cohesionless materials, such an error would maximize the tendency of the pads to slide. Tr. 10535 (Bartlett). However, the results of the Luk analysis show that there was minimal pad displacement under both the design basis earthquake and the beyond-design basis 10,000 year seismic event. Tr. 11516-29, 11575-78, 11586-88, 11610-11 (Luk); Staff Exh. YY. Thus, if the State is correct and the Sandia analysis tends to disregard the cohesive properties of the soil, the actual behavior of the pads in an earthquake should exhibit even less sliding than that predicted by Sandia.

R358. The second alleged deficiency contends that using coefficients of friction in modeling the behavior of the soil foundations violates the intent of the PFS seismic design, which is not to allow the pads to slide on the soil foundation. State F. ¶ 412-414, 425-426. However, the analysis undertaken by Dr. Luk and his colleagues used a variety of interface conditions that alternately maximized the potential for sliding (State Exh. P at 5-6; Tr. 11533 (Luk)), and minimized the potential for sliding (Tr. 11588 (Luk)), in order to determine the potential range of cask behavior at the PFSF site. Even when the potential for sliding was maximized, the displacement that occurred between the cement-treated soil and the underlying soil foundation or the cement-treated soil and storage pad was very small with no significant relative displacements even for the 10,000 year return period ground mo-

other. It probably does not address the question that you just mentioned. Tr. 6786-87 (Luk).

tions. Tr. 11516-29, 11575-78, 11586-88, 11610-11 (Luk); Staff Exh. YY. The displacements observed were "well within the elastic" properties of the soil and cement treated soil. Tr. 11529, 11578 (Luk). Thus, the State's concerns regarding potential sliding of the pads and the minimization of the inertial forces acting on the storage casks are unwarranted, because the pads do not slide, even when such sliding is facilitated by the choice of model parameters.

R359. The third deficiency with the Sandia model of the foundation soils alleged by the State is that it does not account for the post-yield behavior of the Upper Lake Bonneville clays. However, Dr. Luk explained that such effects are not significant and, after a few months of evaluations, he and his team decided that using an elastic model to simulate the soil foundation was adequate. Tr. 11548. (Luk).[190]

R360. The last deficiency raised by the State against Sandia's methodology is that Sandia erred by using the soil properties provided by Geomatrix to Holtec rather than the soil properties developed by Stone & Webster. State F. ¶ 415. This allegation is wrong on two counts. First, Stone & Webster did not develop dynamic soil properties, but also used those developed by Geomatrix in that it used dynamic loads on the casks obtained from ICEC's design calculation, which in turn used the results of Holtec's dynamic analyses that utilizes the soil properties developed by Geomatrix. Tr. 6183, 6235-37, 6340 (Trudeau). Second, by using the Geomatrix soils properties as input to the computer model, Sandia incorporated soil cohesion into its analysis. Tr. 11573-75 (Luk). While Dr. Bartlett disputes that it is possible to incorporate soil cohesion from the dynamic soil properties provided by

[190] Dr. Luk's conclusion is consistent with the opinion of PFS's geotechnical expert Mr. Trudeau, who testified that the Upper Lake Bonneville soils had far more strength that the State credited them. Tr. 6278 (Trudeau). Even the State's witness Dr. Bartlett acknowledged that the clays have a strength in excess of 2,000 pounds per square inch and are only "soft" when compared with an adjacent soil cement layer. Tr. 11335 (Bartlett).

Geomatrix, see State F. ¶ 419, he is not an expert on the features of the ABAQUS code, as Dr. Luk is. Dr. Luk testified that incorporating soil cohesion is among the features of the ABAQUS code. Tr. 11574-75, 11854 (Luk). He knows this for a fact because he studied the manuals for the ABAQUS code. Tr. 11854 (Luk).

g) Young's Modulus

R361. The State asserts that the use of a 270,000 psi Young's modulus for the cement-treated soil underlying the pads at the PFS is a defect of Sandia's model of the PFSF foundations. State F. ¶¶ 427-432. With respect to the significance of this alleged defect, the State asserts without citation to the record that "the State's expert testified that nonlinear models are extremely sensitive to input parameters . and was unwilling to hazard a guess at the effect" of this deficiency. State F. ¶ 431. It is a deep mystery where the State got the testimony it quotes without attribution. Dr. Bartlett listed the 270,000 value of Young's modulus as part of a long answer to a request by State counsel that he enumerate the problems he found with the Sandia model. See Tr. 10374-78 (Bartlett). Nowhere in that answer did Dr. Bartlett refer to the significance of the choice of Young's modulus, and he certainly did not express any unwillingness to "hazard a guess" as to the effect of the choice.

R362. Dr. Luk, on the other hand, was examined extensively on the choice of Young's modulus for his analysis and the significance of this choice. Tr. 11542-46, 11624-34 (Luk). He testified that the results of the cask stability analyses are not sensitive to the choice of Young's modulus because the Young's modulus was a ratio of vertical forces, whereas the significant forces were horizontal (shear) forces. Tr. 11631 (Luk). Moreover, Dr. Luk testified that his use of a higher value

(270,000 psi) of Young's modulus than the 75,000 psi the design called for conservatively maximized the seismic loads transferred from the underlying soil foundation to the storage pad and cask and therefore maximize the potential for horizontal cask displacement due to sliding, cask rotation and potential tipover. Tr. 11544, 11624-25 (Luk). Thus, the evidence of record clearly demonstrates that the use of a higher value of Young's modulus does not affect the accuracy of the results and is in fact a conservative feature of the Sandia model.

h) Pacoima Dam Earthquake Time Histories

R363. State F. ¶¶ 433-438 criticize one of the sets of seismic time histories used as inputs to its model. In the Sandia analyses for the PFSF, three different sets of seismic conditions were modeled: (1) the 2,000-year return period earthquake for the PFS Facility site; (2) the 10,000-year return period earthquake for the PFS Facility site; and (3) a sensitivity study based on the 1971 San Fernando Earthquake (Pacoima Dam record). Luk/Guttman Dir. at A6. The analyses thus modeled ground motions for the design basis 2,000-year event; the 1971 San Fernando Earthquake (Pacoima Dam record), for which the ground motions are somewhat similar to the ground motions of the PFS 2,000-year event; and ground motions for the PFS 10,000-year event, which significantly exceed the design basis ground motions for the proposed PFSF. Id.

R364. The reason for using the Pacoima Dam earthquake time histories as one of the sets of seismic inputs to the analysis was to obtain results using actual earthquake data to validate the analyses conducted with the 2,000 year and 10,000 year earthquake time histories, which are "artificial." Tr. 6817-18 (Luk). The Pacoima Dam runs were thus considered "sensitivity" analyses. Luk/Guttman Dir. at A6.

R365. Oddly, the State oddly attacks the use of the Pacoima Dam earthquake time histories by Sandia as "not representative of the expected seismic conditions at the PFS site." State F. ¶ 438. It further charges that use of the Pacoima Dam time histories "does not satisfy the using [sic] multiple time histories as provided in ASCE 4-98." In both respects, the State misunderstands the purpose and evidentiary value of the confirmatory analysis that Dr. Luk undertook by using real-world earthquake time histories in his models.

R366. The State notes that the acceleration time histories for the Pacoima Dam are lower than those for the 2,000-year return period DBE for the PFSF. State F. ¶ 433. The State also brings up the fact that Dr. Luk did not know the location of the Pacoima Dam epicenter compared with that for the earthquake time history for the PFSF site. State F. ¶ 435.[191] Finally, the State claims that the Pacoima Dam time histories were not matched to a target spectrum and as such are not representative of an evaluation earthquake for the PFS site. State F. ¶ 436.[192] However, as noted

[191] In so claiming, the State omits to point out that Dr. Luk testified that his colleague Mr. Po Lam was the one who obtained the Pacoima Dam information and concluded that the Pacoima Dam event was a good model to use for the PFSF.The actual exchange at the hearing went as follows:

> Q. Do you know how close to the location of the PFSF site is the source of the earthquake, or would the source of the earthquake waves be?
>
> DR. LUK: I don't know the exact locations but I did try to look at the map. And by not going through all the size characterizations, I have to resort to my contract with Mr. Lam. And he did indicate that if someone had to pick a site, that is probably a good choice.
>
> Q. So in other words, the distance from the epicenter to the observation point for the Pacoima Dam earthquake would be a good choice if you wanted to compare that to the PFSF site?
>
> DR. LUK: Yes. Mr. Lam. And he did indicate that if someone had to pick a site, that is probably a good choice.

Tr. 7005-06 (Luk).

[192] The State cites Dr. Bartlett's testimony (Tr. 11702) as authority for the proposition that the Pacoima Dam earthquake is not representative of an evaluation earthquake for the PFSF site. In the first place, Dr. Bartlett is not an expert on earthquake modeling or characterization, so

above, the analyses conducted using the Pacoima Dam time histories were intended to calibrate the model by determining how the PFSF-specific model is model performed using real-world earthquake data. The Pacoima Dam analyses were not intended to be used to predict the behavior of the storage casks and pads at the PFSF in a 2,000 year or 10,000 year event, thus the criticisms leveled by the State, even if correct, would be of no relevance.

R367. The State also raises an argument that the Pacoima Dam earthquake record is not representative of the expected seismic conditions at the PFS site and does not satisfy the using multiple time histories as provided in ASCE 4-98. State F. ¶ 438. This argument is specious for several reasons. No party has claimed that the Pacoima dam earthquake record was used to comply with the recommendations in industry standard ASCE 4-98. Moreover, the State sought to raise this issue in rebuttal examination of Dr. Bartlett and Dr. Bartlett's testimony was stricken as out of scope, thus it is -- to use the State's phrase -- "a bold gesture" for the State to bring it up it in its findings. See Tr. 11701-03. Lastly, on the merits, there is no requirement that a seismic analysis such as Sandia's comply with the recommendations in ASCE 4-98. As fully discussed by PFS in its proposed findings, NRC guidance (Section 3.7.1 of NUREG-0800 and Section 5 of NUREG-1567) allows the designer a choice between two alternative methods for developing design time histories. One approach is to use multiple sets of time histories that in the aggregate envelop the design response spectra, although any individual time history may fall well below the design spectrum at some frequencies. The second

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his testimony has little probative value since it goes beyond the bounds of his expertise. More importantly, Dr. Bartlett testified that he understood, and had no problems with, the way that the Pacoima Dam had been used by Sandia. He stated "One would like to run a real time history through and see the effective of that." Tr. 1170~~2~~ (Bartlett).

[sic] 1

approach is to develop a single set of time histories that envelops the design response spectra and a target power spectral density function. Time histories developed using the second approach are often called spectrum-compatible time histories. See PFS F. 362-371. Thus, this objection by the State to the Sandia analysis has no merit.[193]

R368. The State asserts that the "Luk cask stability analyses did not model the appropriate site conditions at the PFS site" and cannot be used to support a conclusion that the HI-STORM 100 cask will not tip over under either a 2,000-year or 10,000-year return period earthquake at the PFSF site. State F. ¶ 439. Based on the foregoing discussion, it is clear that this proposed findings has no support in the record. Contrary to the State's views, the Sandia cask stability analyses do model the appropriate site conditions at the PFSF site and demonstrate persuasively that the HI-STORM 100 casks will not tip over under either a 2,000-year or 10,000-year return period earthquake at the PFS site.

i) Comparison of the Holtec-Luk Results

R369. As its title indicates, the last section of proposed State findings on the Sandia analyses purports to draw a "comparison of the Holtec-Luk results." Conspicuous for its absence, however, is any comparison between the two most important sets of analyses, i.e., those conducted by Holtec and Sandia for the design basis 2,000 year return period earthquake. This is not surprising, because the results of both sets of analyses are in reasonable agreement, particularly taking into account the methodological differences. For the 2,000 year design basis earthquake, the Holtec analysis using the upper bound coefficient of friction of 0.80 showed a

[193] It is peculiar, to say the least, that the State raises the multiple time histories issue as a collateral attack on the analyses performed by Sandia but has proposed no findings on the issue with respect to the use by PFS of a single set of time histories.

maximum displacement of the cask on the order of 3 to 4 inches with a corresponding maximum angle of rotation of 1.026 degrees. Soler/Singh Dir. at A36. In the Sandia analyses, the maximum horizontal cask sliding displacement produced by any 2,000 year DBE simulation was 3.98 inches, Luk/Guttman Dir. at A13, and a maximum cask rotation angle of 0.40 degrees or less was achieved out of all models examined. Luk/Guttman Dir. at A16.

R370. The State does compare the Holtec and Sandia results for the beyond-design basis 10,000 year return period earthquake. The comparison the State chooses to draw, however, is not between the "base case" for both sets of analyses, but between the Sandia base case and a worst case parametric study conducted by Holtec in which a damping of 5% was assumed and the soil parameters were artificially "tuned" to the resonant frequency of 5 Hz. State F. ¶ 444. Not surprisingly, Holtec predicted greater cask movements than Sandia – a maximum displacement of 56 inches and a rotational angle of 5.37 degrees (for cask 1), versus 7.3 inches of displacement and a maximum angle of rotation of 1.16 degrees for Sandia's analysis.[194] While the State emphasizes the differences in numerical results, it refuses to acknowledge the <u>fundamental</u> feature of both sets of analysis, i.e., that all analyses conducted by both organizations predict no excessive cask displacements and no cask tipover.

R371. The State includes in this section also a comparative discussion of the Holtec analyses of the 2,000 year DBE using DYNAMO and VisualNastran. State F. ¶¶

[194] The displacement for cask 1 for the lower bound soil property case was a maximum displacement of 22.7 inches and a rotational angle of 4.51 degrees. PFS Exh. 86 D, Case ll.

442-43. ~~While reporting~~ It reports the results for the "base case" 2,000-year DBE using DYNAMO and VisualNastran, which are remarkably close.[195]

R372. The State goes on to point to a claimed contradiction between the base DYNAMO and Visual-Nastran cases and one of the runs performed by Holtec for testing the sensitivity to changes in contact stiffness damping values. State F. ¶ 443. It professes that great differences exist because cask 5 on the sensitivity run had a maximum displacement of 10.5 inches, more than double the measured displacements for cask 1 on the two base cases and for cask 1 on the sensitivity run. Id. It making these assertions, the State ignores that (1) the maximum angle of rotation for cask 5 on the sensitivity run would only be 2.23 degrees,[196] far from tipover and representing a safety factor of more than 13 (29.3/2.23) and (2) the contact stiffness values for the three runs ranged from 18.8 x 10^6 to 454 x 10^6 lbs. per inch[197] and the damping values for the three runs ranged from 4.9% to 27.5% critical damping. Thus, given the wide range of values for the different runs and the large safety factor for the cask with the largest displacement on the various runs shows that the State's claimed differences are greatly exaggerated. As Dr. Soler stated, the sensitivity studies show that despite the wider range in input values the displacements are inches, and not feet, as claimed by Dr. Khan and the State. Tr. 9676 (Soler).

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[195] As stated in State F. 442, the DYNAMO base case results for the 2,000 year DBE yielded for cask 1 a maximum displacement of 3.08 inches at the top of the cask and a maximum angle of rotation of .741 degrees, whereas the same case on VisualNastran showed a maximum displacement at the top of cask 1 of 3.7 inches and a maximum rotation of .916 degrees.

[196] This number, previously referenced in the discussion of the State's claims concerning the Holtec cask stability analysis, is calculated applying the formula on page 14 of PFS Exh. 86 D to the maximum peak to peak displacement of cask 5 of 18 inches. See PFS 225 at 29.

[197] As noted earlier, the State incorrectly uses 464 x 10^6 lbs. per inch as the contact stiffness for the DYNAMO runs, State F. ¶ 443, whereas the correct value is 454 x 10^6 lbs. per inch. Singh/Soler Dir. at A144.

R373. Without further elaboration the State also asserts that the multiple analyses with different number of casks and assumptions that Holtec did for the 10,000 year beyond-design basis raises additional uncertainties and do not support the Holtec 2,000 year earthquake analyses." State F. ¶ 443. This assertion is totally unsupported and wrong. The State fails to identify any such uncertainties, and as stated above, the beyond design bases analyses run under a range of worst assumptions uniformly show significant margins against tipover even under 10,000-year earthquake conditions.

R374. In ~~State~~ State F. ¶ 445 the State summarizes ~~the~~ its numerous assertions concerning cask stability. For the reasons set forth in this section above the State's claims lack merit.

G. Section E of Contention L/QQ: Bases for Granting Seismic Exemption Request

1. Overview

R375. The State prefaces its proposed findings for Section E by suggesting a host of issues and uncertainties involving PFS's exemption request that the State claims must be considered by the Board in deciding whether PFS's request to use a 2,000-year return period DBE for the PFSF provides an adequate level of safety. State F. ¶¶ 447-50. However, the issues and uncertainties referred to by the State are either non-existent or have already been incorporated or considered in the determination of the 2,000-year DBE.

R376. One such issue identified by the State is whether the acceptable level of risk should be based on annual or facility lifetime risk. State F. ¶ 447. The weight of the evidence shows, however, that risk is judged and compared on an annual basis, not a lifetime basis. This is the approach used by the Commission in its probability risk standards, as well as the by Department of Energy ("DOE") and other regulatory body and code authorities. See PFS F. ¶ 489-95.

R377. The State also asks "[d]oes Dr. Cornell's assertion of conservatism in the ISFSI design approach assure a sufficient margin of safety?" State F. ¶ 447. First, the conservatisms in the PFSF design and the margin of safety it provides are not mere "assertions" of Dr. Cornell's. The existence of these conservatisms and the related risk reductions factors on the order of 5 to 20, which are embedded in the design procedures and acceptance criteria of the NRC's Standard Review Plans ("SRPs"), have been established through comprehensive seismic probabilistic risk assessments ("PRAs") and seismic risk margin studies undertaken over the course of many years for many nuclear power plants. PFS F. ¶¶ 430. PFS has also performed analyses of its own and shown that large margins of safety exist such that the proposed PFSF would be able to withstand an earthquake with a mean annual return period on the order of 10,000 years, far more severe than the design-basis 2,000-year return period DBE. Cornell Dir. at A54-A55.

R378. Another such issue is whether "the Staff put forward a well-founded rationale for accepting a 2,000-year return period value with the PSHA methodology." State F. ¶ 447. That is not, however, the ultimate issue before this Board, which is whether the use of a 2,000-year return period earthquake is adequately protective of the public health and safety. See PFS F. 400. Therefore while the Staff's rationale for approving the exemption request is relevant, ultimately what is important is not the Staff's rationale but the sufficiency of the evidence to establish adequate protection of the public health and safety. Such evidentiary support may be provided by either the Applicant or the Staff, or both. PFS Conclusion of Law 7.

R379. With respect to its asserted uncertainties, the State claims that greater uncertainty exists in seismic hazard assessments for the Intermountain West region, where the site of the PFSF is located, than those for other regions of the country. State F. ¶¶ 448-49. However, it is undisputed that a key advantage of the probabilistic seismic hazard analysis ("PSHA") method is its capability to take account of the uncertainties in the available knowledge of key elements of the seismic hazard. Cornell Dir. at A16; Tr. 8259-60 (Stamatakos/McCann). Dr. Arabasz agrees that the PSHA conducted for the PFSF is adequate and he had high praise for the effort undertaken in developing the PSHA for the PFS site. PFS F. ¶ 466. Indeed, Dr. Arabasz stated that Applicant's seismic source investigation that identified the east and west faults greatly reduced the uncertainty of one of the key inputs used for determining seismic hazard. Tr. 10164 (Arabasz).

R380. The State specifically refers to Dr. Arabasz's testimony that the mean return period for earthquakes along the Stansbury fault is longer than for the Wasatch front and that the Stansbury fault has been storing up energy for 8,000 years and is capable of delivering a large earthquake. State F. ¶ 449, citing Tr. 9203-04 (Arabasz). From this testimony (and the alleged uncertainties in earthquake hazard assessment discussed above), the State requests the Board be mindful of both the "potential energy that may be unleashed at the Skull Valley site" and "the uncertainties in earthquake forecasting" and as a result "be circumspect when evaluating the safety of the PFS facility." Id.[198]

[198] The State does not clarify what it means by its request that the Board be "circumspect," a plea that permeates its proposed findings. See State F. ¶¶ 256, 449. If the State is trying to suggest that the Board impose a higher burden of proof on the Applicant than the "preponderance of

R381. The cited testimony by Dr. Arabasz was, however, given in the context of responding to the Board's questions for "an appropriate level" for the return period of the design basis earthquake ("DBE") disregarding "completely" the conservatisms incorporated into the applicable design procedures and standards. Tr. 9200, 9206 (Arabasz). Nowhere did Dr. Arabasz suggest that the relatively longer return period along the Stansbury fault would make the 2,000-year mean return period DBE inappropriate when evaluated under the "two-handed approach," which looks both at the mean annual probability of exceedance of the DBE and the conservatisms of the design (an approach he "emphatically" agrees is the appropriate approach for evaluating the adequacy of the 2,000-year DBE). Tr. 9120-21, 10048 (Arabasz). In this respect, he agreed with Dr. Cornell that a performance objective of 1 x 10^{-4} was appropriate for the PFSF and concluded that if Dr. Cornell's evaluation of the PFSF conservatisms were correct, this performance objective would be met. Tr. 10154-55 (Arabasz). The proposed State findings never acknowledge Dr. Arabasz's conclusion.

R382. Thus, the State inappropriately implies, contrary to Dr. Arabasz's testimony, that the Board should disregard the application of the "two-handed approach" to the seismic exemption request. Indeed, focusing exclusively on the potential magnitude of an earthquake from a single fault, as suggested by the State (State F. ¶ 449), would be to apply a deterministic hazard methodology. Dr. Arabasz as well as the other witnesses were very clear that the probabilistic approach was the preferable method by which to determine the DBE for the PFSF. Tr. 9116-19 (Arabasz). See also Cornell Dir. at A11-A18.

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the evidence" standard imposed by Commission regulation, such a suggestion is contrary to the law and must be rejected. See Section II, supra.

R383. The State also claims that both PFS and the Staff are improperly suggesting that the capacity, or the design side, of the two handed approach should "do all the heavy lifting." State F. ¶ 450. This issue was raised by the Board itself, when it questioned whether the application of the "two-handed approach" resulted in the "design robustness hand" doing more than its share of the lifting than the "hazard level hand." Cornell Reb. A3; Tr. 10047-48. (J. Lam). Dr. Cornell, however, laid that concern to rest, explaining both the origin and the allocation of functions between the magnitude of the DBE and design conservatism as well as the balance that exists between the two. Cornell Reb. at A3; Tr. 12961 (J. Lam). The State rhetorically questions whether one can be confident that the asserted conservatism in design has indeed been achieved, in light of its unsupported assertion that "the reference frame for ISFSI SSC failure probabilities is, at best, in a nascent state of development." State F. ¶ 450. However, the same design codes and standards that provide for the robustness of nuclear power plant ("NPP") design are generally applicable to ISFSIs, and would provide the same level of conservatism for typical structures and components designed to those codes and standards.[199] For the storage casks, which are not typical NPP structures or components, two independent analytical models demonstrated the conservatism of the cask's design. PFS F. 449-50. Thus, there is ample evidentiary basis on which to conclude that the "design robustness hand" and the "hazard level hand" are in fact carrying their customary and appropriate weight.

[199] Cornell Dir. at A34-A39. In addition, PFS has identified large conservatisms in its design of the CTB and the storage pads that confirm the conservatism of their design. See PFS F. ~~***~~ 255-256, 434.

2. Benchmark Probability for the DBE at the PFS Site

R384. The State claims that "[i]t is evident that at the low end, the DBE benchmark for the PFS site sensibly must be at least 2,500 years." State F. ¶ 467; see also id. at ¶¶ 464-66. Despite the State's claim that this assertion is self evident, the record contains no credible evidence to support it and none is cited by the State. The sole support for the statement is the fact that Utah interstate highway bridges, certain buildings under the IBC code, and PC-3 facilities under DOE-STD-1020-2002, all use a 2,500-year DBE. Id. However, none of the State's experts testified that this fact mandates that the low end of the DBE benchmark for the PFS site must be at least 2,500 years. While the pre-filed testimony of Dr. Bartlett had contained the virtually identical conclusion, Bartlett Section E Dir. at A9, on cross-examination Dr. Bartlett disavowed the claim that "solely on that basis, PFS' use of a 2000-year design basis earthquake is inappropriate." Tr. 12808-09 (Bartlett).

R385. Dr. Bartlett explained that the statement in his pre-filed testimony was "historical" and reflected the State's initial concerns that PFS's use of a 2,000-year DBE was based on just a "one-handed approach" which focused solely on the magnitude of the DBE and neglected to consider the conservatisms necessary to meet a specified performance goal. Tr. 12808-11 (Bartlett). He acknowledged, however, that Dr. Cornell's testimony had fully endorsed and applied the two-handed approach. Id. Dr. Bartlett further recognized that "[w]e have to use a two handed approach," and under that approach PFS's use of a 2,000 year design basis earthquake is not inappropriate simply because other standards use a DBE of 2,500 years. Tr. 12808-09 (Bartlett).

R386. Similarly, Dr. Arabasz disavowed Dr. Bartlett's prefiled testimony that PFS's use of a 2,000-year DBE was inconsistent with other standards using 2,500 years. Tr.

9187-88 (Arabasz). He agreed that one could not reach such a conclusion "without evaluating the conservatisms embodied in the relative earthquake designs" of the PFSF compared to those provided for by the other standards. Id.

R387. Notwithstanding the testimony of its own experts (which it pointedly ignores), the State blithely puts forward the position repudiated by its own experts that use of a 2,000-DBE for the PFSF is inappropriate solely because other standards use a 2,500 mean return period DBE. State F. ¶ 467. Such a finding is contrary to the evidence and must be rejected.

R388. The State goes to claim that "[i]n addition to an inadequate margin of safety, there is a public policy concern that by allowing a 2,000-year DBE for the PFS nuclear facility it will have a lower DBE than that now required by other standards," and that "[a]t a minimum, setting the DBE for a nuclear facility lower than that for other non-nuclear structures or DOE PC-3 facilities poses a real public perception problem." State F. ¶ 467. The issue raised by contention Utah L/QQ is not an alleged public perception problem, but a public health and safety issue. Public perception is not an appropriate relevant standard on which to base licensing decisions. Cf. Metropolitan Edison Co. v. People Against Nuclear Energy, 460 U.S. 766 (1983). Indeed, as just discussed, the State's own experts have testified that it would be wholly inappropriate to reject a 2,000-year DBE for the PFS simply because the numerical DBE was lower than that for other facilities.

R389. The clear weight of the evidence shows that the level of safety of the PFSF designed to a [numerical] 2,000-year DBE following NRC mandated nuclear safety standards provides at least twice the level of safety attained by highway bridges or buildings and facilities designed under the IBC to a numerically higher DBE of 2,500 years, but subject to less stringent design safety standards. Cornell Dir. at

A90-94. Thus, the State's claim that "at the low end, the DBE benchmark for the PFS site sensibly must be at least 2,500 years," State F. ¶ 467, must be rejected as totally unsupported by the record.[200]

3. Staff's Rationale for PFS's Seismic Exemption

R390. In the next section of its proposal findings, the State attacks as unsound the Staff's rationale for approving the exemption. State F. ¶¶ 469-94. However, as set forth above, the ultimate issue before the Board is not the Staff's rationale for approval of the exemption, but the sufficiency of the evidence supporting a 2,000-year return period DBE for the PFSF as adequately protective of the public health and safety. As the State has noted in other contexts, the status of the Staff in this proceeding is that of another party. See State F. at ¶ 8. Thus, it is the Board's decision and rationale, and not that of the Staff's that will constitute the substantive decision subject to Commission and judicial review. It is from this perspective that we examine the State's challenges to the Staff's rationale.

R391. The State refers to several justifications for the exemption that the Staff had previously advanced, but which – as the State itself recognized, see State F. ¶ 470 - are not currently advanced as part of the Staff's case in this proceeding. State F. ¶¶ 471-73. Justifications that the Staff may have previously offered for granting the exemption that ~~which~~ are not currently part of the Staff's case are clearly irrelevant.

[200] In addition, the State proposes a long series of findings (State F. ¶¶ 451-463) in which the State argues its position that the upper-end DBE benchmark for a nuclear power plant located at the PFSF site would be a 10,000-year return period earthquake, instead of the 5,000 years postulated by the Staff. In PFS's view, the ultimate resolution of this dispute does not affect the appropriateness of the exemption sought by PFS because the evidence on the record shows that the safety-related structures and components ("SSCs") at the PFSF would meet safety standards regardless of which of the NPP design standards is used as a reference. See PFS F. ¶¶ 470-71, 479.

R392. Citing the Staff's reliance on the Commission's statement that ISFSIs pose a lower radiological risk than NPPs, the State argues that the lower radiological risk posed by ISFSIs "does not in and of itself" justify a five fold decrease in the design basis earthquake for a NPP of 10,000-years to a 2,000-year design basis earthquake for an ISFSI. State F. ¶ 474. However, nobody has made the argument that the State seeks to refute; neither the Staff nor the Applicant rely solely upon the lower risk of ISFSIs vis-à-vis NPPs as the basis for granting the exemption. Rather, as agreed by the witnesses for all the parties, the lower radiological risk of an ISFSI compared to a NPP establishes the DBE for a new NPP as an upper end probability benchmark for the PFSF DBE. PFS F. ¶ 414.

a) DOE Standard 1020.

R393. The State criticizes what it claims is the Staff's "partial reliance" on DOE STD 1020 to justify a 2,000-year return period because the Staff allegedly "eschews the DOE design approach that fundamentally and quantitatively couples the MAPE (Mean Annual Probability of Exceedance) for any DBE with a target seismic performance goal." State F. ¶ 475. However, as the State acknowledges, PFS fully embraces the "two-handed approach" embodied in DOE-1020 and justifies the exemption request in terms parallel to DOE's risk reduction performance standard. Id.; see also PFS F ¶¶ 411-453. As set forth below, the clear weight of the evidence shows that the PFSF design achieves a performance goal on the order of 1×10^{-4}, equivalent to the goal for ISFSIs under DOE-STD-1020. Therefore, the State's concerns about the Staff's asserted "partial reliance" on DOE-STD-1020 is not an issue here.

b) INEEL Exemption for TMI-2 ISFSI

R394. The State likewise claims that the NRC's reliance on its grant of the INEEL exemption as precedent for adopting a 2,000-year DBE for the PFSF is misplaced because differences between the PFSF and the INEEL site and other factual differences do not make the INEEL exemption a "compelling precedent," and thus, according to the State, it is of "little if any bearing in this case." State F. ¶ 478. While the substantive issue of whether the 2,000-year DBE for the PFSF is adequately protective of public health and safety is not controlled by the INEEL exemption, the NRC's granting of the INEEL exemption has relevance to this case: It reflects the NRC's considered decision that a 2,000-year DBE was appropriate for the INEEL ISFSI because the 2,000-year DBE was adequately protective of public health and safety.

R395. The differences claimed by the State to exist between the INEEL ISFSI and the PFSF are of little import. The State first claims that the INEEL ISFSI is located on large federal reservation with the nearest resident tens of miles away; in contrast the PFSF is located within two miles of the nearest resident and the land to the north of the site is contiguous with privately owned land. However, the evidence clearly shows that a 2,000-year DBE for the PFSF would provide adequate protection of public health and safety of nearby residents. <u>See</u> Section IV.H, <u>infra</u>. Even assuming the casks were to tip over during a seismic event – which would not occur even under the 10,000-year ground motion – the radiological dose consequences at the site boundary would remain below the NRC's 5 rem accident limit. <u>Id.</u>[201]

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[201] The State claims that the land to the north of the PFS site could some day be developed for residential uses. State F. ¶ 477 (citing Tr. at 12579-82 (Donnell)). There is absolutely no evidence on the record to show that such development is likely to occur over the projected life of the PFSF. Even assuming that it were to occur, it would be simple to provide additional radia-

R396. The State further claims that at the INEEL site the ground motions are 0.30 g for a 2,000-year and 0.47 g for a 10,000-year mean return period ("MRP") earthquake respectively, and that the INEEL ISFSI was designed to a 0.36 g horizontal design value, which means its ground motions fall somewhere between a 3,000- to 4,000-year MRP. State F. ¶ 476. While the INEEL ISFSI was designed to a higher ground motion than that for the 2,000-year MRP earthquake, the exemption was approved on the basis of the adequacy of the 2,000-year MRP earthquake. The safety evaluation for the exemption expressly states that the "DOE Standard 1020 risk graded approach of using the 2000-year return period mean ground motion as the DE is adequately conservative," and concludes that the design earthquake of 0.36g for the INEEL ISFSI is acceptable because it exceeded the 0.30g value for the 2,000-year MRP. Staff Exh. S, Final Evaluation of Exemption Request to 10 CFR 72.102(f)(1) Seismic Design Requirement, at 3, attached to May 28, 1998 letter from NRC to INEEL ~~(emphasis added)~~. The design of the INEEL ISFSI to a higher level than a 2,000-year DBE does not change the DBE standard upheld by the NRC there.

R397. Finally, the State claims that spent fuel at INEEL is stored in 30 horizontal concrete modules that under earthquake conditions are not expected to slide. State F. ¶¶ 475-76. In contrast, PFS will store up to 4,000 casks using an asserted "unconventional design" in which "sliding of the casks and the pads under earthquake conditions" is considered "to be beneficial because sliding dissipates seismic energy that the casks and foundations would otherwise have to resist." State F. ¶ 477 The larger number of casks to be stored at the PFSF has been accounted for

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tion protection to the public, should it be deemed appropriate to do so. For example, PFS could construct an earthen berm. Tr. 12583 (Donnell).

in evaluating whether the exemption adequately protects public health and safety. Singh/Soler/Redmond Dir. at A25-28; Waters Dir. at A20-21. We have already discussed above the State's repeated mischaracterization of the PFS design as unconventional and the State's meritless claims regarding potential sliding of the casks and the pads.

R398. Thus, the differences alleged by the State between the ISFSI at INEEL and the PFSF are erroneous and irrelevant. The INEEL exemption corroborates the appropriateness of granting an exemption to PFS based on a determination that a 2,000-year DBE for the PFSF provides adequate protection of the public health and safety.

c) Geomatrix Probabilistic Seismic Hazard Analysis

R399. The State also challenges the Staff's determination that Geomatrix produced a "conservative" PSHA for the PFS site. The State acknowledges that the Geomatrix investigators who conducted the PSHA for the PFS site are "highly competent" and that Geomatrix conducted "an adequate PSHA to depict the potential hazard at the PFS site." State F. ¶ 479. The State argues, through, that the PSHA performed for the PFS site is not "conservative" to the extent attributed to it by the Staff, and thus the Staff cannot rely on its claim ~~of~~ that the Geomatrix PSHA is conservative to support the grant of the PFS exemption. State F. ¶ 479; see also id. at ¶¶ 480-94.

R400. Among other points, the State argues that the Geomatrix PSHA for the PFSF should not be considered conservative because the Staff's analysis and evidence supporting the conservative nature of the Geomatrix PSHA merely constitutes "one" party's analysis "subject to scientific challenge." State F. ¶ 479. According to the State, "[c]entral to a well executed PSHA is capturing the technically supportable and legitimate range of informed opinion representing the whole scientific community on specific aspects of the PSHA." State F. ¶ 480.

R401. The point that the State appears to be making is that while the Staff's analysis may present one legitimate viewpoint, it is subject to scientific dispute, and other viewpoints may be equally, if not more, valid scientifically. Because a proper PSHA is to capture the legitimate range of informed opinion, the Staff's analysis that the Geomatrix PSHA is conservative, according to the State, cannot be accepted to the exclusion of other equally valid opinions that the Geomatrix PSHA is not conservative, such as Dr. Arabasz's. (Tr. 9861-63, 9878-79, 10128-31 (Arabasz)). The State thus acknowledges that the Staff's analysis constitutes an "informed opinion" that the uncertainties in the seismic hazard analysis embodied in the PSHA are actually tilted toward making the resulting 2,000-year prediction conservative.

R402. Second, while the State engages in a lengthy analysis as to why the Geomatrix PSHA is adequate, but not conservative, there are certain elements of conservatism that appear beyond dispute. For example, the State offers no substantive response and cites no witness testimony contesting the Staff's observation that the ground motions at the PFSF site computed by Geomatrix are higher than those at sites in the I-15 corridor in the Salt Lake Valley or that the West fault is a splay of the large East fault incapable of independently generating large magnitude earthquakes. See State F. ¶¶ 484, 488. However, it is unnecessary to rely upon any such conservatisms to conclude that the exemption request is adequately protective of public health and safety. Rather, as will be discussed below, the record shows that the PFSF would be able to withstand a beyond design basis earthquake with a return period on the order of 10,000-years wholly apart from any conservatisms in the Geomatrix PSHA. As such, as the State agrees would be the case in such a circumstance, see Tr. 10154-55 (Arabasz), the 2,000-year DBE for the PFSF is adequately protective of public health and safety.

4. Establishing Risk Graded Design Basis Earthquake Standard

a) Performance Goals

R403. The State asserts that under a risk-graded approach to seismic design, the "design procedures and acceptance criteria include conservatisms that are intended to implement" performance goals, citing to Dr. Cornell's testimony. State F. ¶ 495 (emphasis added). However, implementing a performance goal by the inclusion of conservatism in a set of design procedures and acceptance criteria may be either implicit or explicit. Cornell Dir. at A25. In many cases, the conservatisms are not explicitly stated, but are embedded in the design procedures and the various codes and standards pursuant to which the design is accomplished. Id. Thus, the risk reduction factor, R_R, achieved by the conservatisms embodied in a set of design procedures and acceptance criteria may not necessarily be reduced to a numerical value and correlated with a specific performance goal, as is done under the formal regime established by DOE-1020.

R404. The State states that "in response to Judge Lam's concern that there are 'substantial uncertainties associated with any probabilistic assessment,' Dr. Cornell testified that in computing the failure probability of SSCs, uncertainties must be factored into any estimates of safety margins. Tr. (Cornell) at 7919-7920." State F. ¶ 497 (State's emphasis). Dr. Lam's question, however, concerned uncertainties in seismic PSHAs, to which Dr. Cornell responded that uncertainties in assessing earthquake conditions, such as the slip rate on faults, are factored into the PSHA, and a properly performed PSHA will capture those uncertainties in earthquake characterizations. Tr. at 7919-7920 (Cornell).[202] Dr. Cornell went on to say that in employing a "probabilistic approach" for evaluating safety margins of structures, i.e., a probabilistic risk assessment ("PRA"), a similar attempt is made to reflect uncertainties. He further stated that it "is not necessary, in my opinion," to perform a PRA for the PFSF to conclude that "the 2,000 year design-basis earthquake will provide failure probabilities . . . low enough for public safety." Tr. 7924 (Cornell).

R405. Dr. Cornell explained that a PRA was unnecessary for those PFSF structures and components for which he concluded by "their analogy with nuclear power plant components" had risk reduction factors of five or more. Tr. at 8019 (Cornell).[203] For others, such as the casks, the beyond-design basis analyses for the 10,000 year earthquake performed by both Holtec and Sandia showed that casks would not tip over even under this beyond-design basis loading. As a result, it is not necessary to go into more refined detail to conclude that failure probabilities are low enough to assure public safety. Tr. at 8019-20 (Cornell). Likewise, the conservatisms in the calculations of the margins of safety against failure of the PFSF foundations are such that it is not necessary to perform more detailed analyses to conclude that the probability of foundation failure is low enough that public safety is assured. Trudeau Section D Dir. at A16-24; Trudeau Soils Reb. At A2-A3.

b) DOE Risk Graded Seismic Design Methodology

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[202] Dr. Arabasz fully agreed that uncertainties are captured in a proper PSHA, that the ability to account for uncertainties using PSHA methods is one of the advantages for using a PSHA, and that Geomatrix conducted a proper PSHA for the PFSF site. See PFS ¶¶ 403, 466.

[203] As discussed elsewhere, the risk reduction factor of 5 to 20 for typical nuclear power plant components is based on seismic PRAs and seismic margin studies, e.g., Cornell Reb. at A3, which would account for uncertainties as discussed in the text above. In other words, both the seismic PSHAs and PRAs underlying the risk reduction ratios account for uncertainties. Tr. 7919-20 (Cornell).

R406. The State notes that DOE STD 1020-02 specifies a risk reduction ratio of 4 for a performance category 3 ("PC3") SSCs such as the PFSF. State F. ¶ 501. Previously, DOE STD 1020-94 had specified a risk reduction ratio of 5 for a PC3 facility. At the same time that DOE changed the risk reduction for a PC3 facility from 5 to 4, it also changed the design earthquake from 2,000 years to 2,500 years such that the overall performance objective remained unchanged at 1×10^{-4}. Cornell Dir. at A28.[204] Since the performance objective for PC3 facilities remained unchanged, these changes are of no consequence to the determination of the appropriate design basis earthquake for the PFSF. Tr. 12807 (Bartlett) ("I don't see any news there."); Cornell Dir. at A28.

R407. The State's discussion of the DOE seismic design and analysis methodology (State F. ¶¶ 498-506) states that the DOE risk reduction factors do not apply to foundations because, according to the State, "extra conservatisms and margins inherent in structural mechanical codes . . . <u>generally</u> don't apply to foundation systems." State F. ¶ 503 (emphasis added). As partial support for this claim, the State refers to a statement by Dr. Cornell's that "it is not entirely clear whether the R_R range conclusion . . . was intended to apply to foundations." <u>Id.</u> (quoting Cornell Dir. at A41). In reality, the cited testimony of Dr. Cornell's did not say that risk reduction factors generally do not apply to foundations. What he said was that the specific "R_R range conclusion" of 5 to 20 for typical nuclear power plant components set forth in Attachment A to his testimony which was "based on

[204] DOE changed the design earthquake for PC3 facilities from 2,000 to 2500 to correspond to USGS national probabilistic seismic hazard maps which use the 2500-year level. Because DOE did not change the 1×10^{-4} PC3 performance goal, DOE simultaneously reduced the risk reduction factor, R_R, for PC3 facilities from 5 to 4 by making the acceptance criteria somewhat less conservative. Cornell Dir. at A28. <u>See also</u> State Exh. 208. This is a good illustration of how different combinations of the MAPE and the design earthquake can provide the same level of seismic performance.

NUREG-6728" and the underlying NPP seismic PRAs and margin studies, might not be applicable to foundation systems. Cornell Dir. at A41; see also id. at A31, A39-A40. Dr. Cornell went on to state that the seismic PRAs and margin studies for NPPs had included "potential foundation failure modes such as overturning, bearing, and sliding" and that these "failure modes did not show up . . . . as being critical failure conditions," which were "all structural and mechanical." Id at 41; Tr. 12952-53 (Cornell). From that fact, Dr. Cornell concludes that the risk reduction factor for potential foundation failure modes is "at least as large" as the 5 to 20 risk reduction factor applicable for NPP structural and mechanical failure modes. Tr. 12953 (Cornell).

R408. Further, as indicated above, there are numerous conservatisms inherent in PFS's analyses of the margins of safety against failure of the foundations due to overturning, bearing and sliding. These include using the static shear strength of the underlying soil rather than its strength under the dynamic loadings; this choice alone by the State's own admission, increases the margin against foundation failure by at least 30 percent. Tr. 12858, 12976-77 (Bartlett). Other factors of conservatism include basing the bearing capacity calculations on the lowest measured shear strength of the soils, ignoring the resistance to sliding of the pads provided by the surrounding soil cement, using very conservative earthquake load combinations, and others. See PFS F. ¶¶ 438-44. Thus, risk reduction factors are provided in the design of the PFSF foundations, whether or not those factors are included in DOE-1020 or NUREG-6728. Whether conservatism is provided by code or by design practice is irrelevant to its existence. See Cornell Dir. at A48-A54.

R409. The State notes that the methodology and standards set forth in DOE Standard 1020 "withstood the scrutiny of extensive technical peer review" and claims that the "NRC Staff's approach to evaluating the performance of ISFSI SSCs is ad hoc and has not evolved to the level of sophistication and technical rigor required by DOE." State F. ¶¶ 504-505. In asserting that the NRC's approach is deficient compared to DOE's, the State completely ignores the long history of NRC evaluation of NPP seismic design as part of its licensing and regulatory responsibilities. The adequacy of NPP seismic design – and accordingly the NRC's "approach to evaluating" seismic performance – has been substantiated by extensive subsequent technical review, e.g., the seismic PRAs and margin studies that have been conducted for NPPs. Cornell Reb. at A3. Therefore, the adequacy of the NRC's approach for evaluating the seismic performance of nuclear facilities has also withstood the scrutiny of extensive technical review.

R410. The State asserts that to "reasonably assure" public health and safety, the DBE for the PFSF "must be formally linked to a specific performance goal and risk reduction ratio." State F. ¶ 506. The State claims that the Staff has not done so in that it "has not established a performance goal (failure probability) for this facility or any previous ISFSIs. Id. However, the State ignores two critical points. First, regardless of whether the Staff formally linked the 2,000-year DBE to a specific performance goal and associated risk reduction factor, the NRC's seismic design criteria and procedures contain numerous inherent conservatisms that give effect to the NRC's defense-in-depth policy, Cornell Dir. at Attachment A. Further, the Staff has analytically confirmed by Sandia's analysis (which shows no cask tipover for the 10,000-year earthquake) that large safety margins exist with respect to the casks. Staff Exh. P. Second, PFS's own extensive analyses of the conservatisms in the PFSF design shows that the risk reduction factor for PFSF SSCs is at least 5 or greater, and on that basis PFSF seismic design meets a performance goal of 1 x 10^{-4}. Cornell Dir. at A54-A55. Thus, the fact that the Staff in its analysis did not formally couple a performance goal and risk reduction ratio to the 2,000-year DBE for the PFS facility is irrelevant here.

c) Evidence of SSCs Probability of Failure or Risk Reduction Ratios

(1) Fragility Curves

R411. According to the State, fragility curves would provide "better assurance in setting and evaluating the lower DBE sought by PFS," and moreover would be useful because there is "no existing data to demonstrate the seismic performance" of the PFSF due to its alleged "unprecedented and untested design." State F. ¶¶ 507-08. Nevertheless , the State reluctantly acknowledges that, absent brittle behavior in the system,[205] fragility curves are not necessary to show that the PFS SSCs meet a performance goal of 1 x 10^{-4} at the specified 2,000-year DBE. State F. ¶ 509. This conclusion is supported by the uncontradicted testimony of both PFS and the State. Tr. 12852-53 (Bartlett); Tr. 8020 (Cornell); Cornell Dir. at A65-A67.[206]

(2) Probability of Failure (Response to State Findings ** 510-511)

R412. The State agrees with Dr. Cornell that one can demonstrate that an SSC meets a performance goal by establishing that the probability of failure is less than the

[205] The State does not claim that the PFSF SSCs exhibit brittle behavior and Dr. Cornell confirms that there are in fact no brittle SSCs at the PFSF. Cornell Dir. at A32.

[206] We disagree with the State's claimed usefulness of fragility curves here because, for reasons stated at length previously, the PFS design is not unprecedented and because the evidence clearly establishes that the PFSF meets a performance goal of 1 x 10^{-4}. See PFS F. ¶¶ 424-53.

specified performance goal. State F. ¶ 510. It claims, however, that such a demonstration is not possible with respect to the PFSF because of unresolved uncertainty in PFS's analyses challenged in Section D of Utah L/QQ. State F. ¶ 511. As discussed in Sections IV.C through IV.F above, the State's claims raised in Section D are without merit. Thus, the State's claimed "unresolved uncertainty" does not exist and is no bar to determining that the PFS SSCs meet a performance goal of 1 x 10^{-4}.

(3) Storage Casks (Response to State Findings ~~***~~ 512-520)

R413. The State claims that Dr. Cornell's opinion that the storage cask will achieve a performance goal of 1×10^{-4} is based on "the cask vendor's <u>unanalyzed prediction</u> of what will occur from strong ground motions generated by a 10,000-year return period earthquake." State F. ¶ 512 (emphasis added).[207] Characterizing Holtec's results for the 10,000-year earthquake as an "unanalyzed prediction" is both surprising and highly inaccurate. Holtec's conclusion that the casks will not tip over under the 10,000-year earthquake is based on a series of nonlinear analyses using various alternative input assumptions and conditions. These analyses are part of the record and were the subject of extensive testimony at the hearing. PFS Exh. 86C, Tr. 5755-88 (Singh/Soler).[208] Further, the Holtec conclusion is confirmed

[207] The State also notes that no PRAs evaluate the design margins or the consequences of casks tipping over. State F. ¶ 512. However, Dr. Cornell testified that the results of the beyond-design basis analyses for the casks show that such PRAs are unnecessary. Tr. 8019-20 (Cornell). Likewise, the State itself admits that fragility curves are unnecessary. State F. ¶¶ 507-09.

[208] In an apparent attempt to diminish the importance of Holtec's beyond-design basis analyses, the State at one point refers to the "eleven [computer] runs" and related "analyses" described in Holtec's Beyond Design Basis report as "an attempt to thwart the State's criticisms of the Holtec 2,000 year report." State F ¶ 270. It is inexplicable how the same proposed findings that refer to Holtec's beyond-design basis analyses as an attempt to thwart the State's criticisms can also deny that they exist.

by a wholly different analytical modeling approach by Sandia that similarly predicts satisfactory performance of the casks for the 10,000 year beyond design basis earthquake on which Dr. Cornell also relied. Cornell Dir. at A52. ~~(Cornell).~~

R414. Further, the State claims that the "record is clear that Dr. Cornell did not review key Holtec analyses" and suggests that little or no credence should therefore be given to Dr. Cornell's opinion that the casks meet a performance goal of 1×10^{-4} based on Holtec's analyses. State F. ¶ 520; see also id. at ¶¶ 513-14. The State's assertion is meritless. As discussed above, it is well established that an expert can rely upon the work of others for the factual underpinnings of his opinion without needing to reproduce it or verify it himself.

R415. Moreover, the record shows that Dr. Cornell satisfied himself of the appropriateness of the methodologies used by Holtec and Sandia in their respective evaluations. He reviewed both the Holtec cask stability evaluation for the 2,000-year DBE (State Exh. 173) and the Sandia Report (Staff Exh. P)[209] and had no concerns with either the methodology or input assumptions used for either analysis. Tr. 7973-74, 7987-88 (Cornell). Dr. Cornell stated that he did not believe he had previously seen the Holtec Beyond Design Basis Report (PFS Exh. 86C) but that he had discussed with Holtec the "basic methods" used in the report. Contrary to the State's claim in State F. ¶ 513, Dr. Cornell's lack of review of the actual re-

[209] Dr. Cornell reviewed Revision 0 of the Sandia Report rather than Revision 1, which was introduced into evidence as Staff Exh. P. The only difference between the two revisions, however, was to add a run for the 10,000-year earthquake using a friction coefficient of 0.8 as well as a run for the Pocoima Dam record. The methodology and input assumptions in Revision 1 were unchanged from Revision 0. Tr. 6864-65 (Luk).

port is of no significance, particularly since Holtec used the same methodology in analyzing both the 2,000 and 10,000-year earthquake events.[210]

R416. The State also claims that, contrary to Dr. Cornell's "opinion that uncertainties must be factored into estimates of safety margins," Dr. Cornell "did not quantify the uncertainties in the cask vendor's nonlinear finite element cask stability analysis," and that therefore PFS has not met "its burden of showing conservatism in SSCs at PFS." State F. ¶ 513 (emphasis added). The State's claimed failure to quantify uncertainties in Holtec's analyses is both irrelevant and wrong for the following reasons:

- First, as noted above, Dr. Cornell's reference to factoring uncertainties into estimates of safety margins was in the context of performing a formal seismic PRA which is not necessary here.

- Second, the State incorrectly asserts that Dr. Cornell concluded that "quantification of uncertainties was not necessary" here "because the major source of uncertainty is nonlinear behavior and Holtec performed a nonlinear analysis." State F. ¶ 513. To the contrary, Dr. Cornell testified – wholly apart from any such potential uncertainty – that one could judge that the PFS design was capable of meeting a performance goal of 1×10^{-4} based on the results of the Holtec and Sandia cask stability evaluations for the 10,000-year earthquake "without going into more refined detail as to exactly how large that margin really is and how much uncertainty there is about it." Tr. 8019-20 (Cornell). Thus, it was not the nature of the analyses that made quantification of uncertainties unnecessary, but the large margins against failure predicted by the results of the analyses.[211]

[210] Similarly, Dr. Cornell's lack of review of the actual Holtec report for the "PFS Site Specific HI-STORM Drop/Tipover Analyses" is of no import. See State F. ¶ 514. Again, Dr. Cornell discussed with Holtec the results of the analysis and how it was performed. Tr. 7976 (Cornell).

[211] It was subsequent to this testimony that Dr. Cornell went on to say additionally that one of the major uncertainties in performing a typical PRA is to project behavior of a structure from the linear regime (in which the design analysis is typically performed) to the nonlinear regime, and thus the nonlinear cask stability analyses performed by Holtec and Sandia served to re-

- Third, the Holtec simulations for the 10,000-year earthquake use a range of bounding, worst-case, and unrealistic assumptions, which give more than adequate account of potential input parameter uncertainties that could affect the results. These included: (1) using upper and lower bound coefficients of friction of 0.8 and 0.2 as well as random coefficients of friction; (2) using unrealistic radiation soil damping of 1 percent and 5 percent, and (3) choosing the stiffness of the soil springs to provide resonance of the cask-pad system with amplified spectral range of earthquake input spectra. Singh/Soler Dir. at A114-A121; PFS Exh. 86C.[212]

- Fourth, Sandia's use of an entirely different methodology to model the 10,000-year earthquake, likewise showing no cask tipover, accounts for potential uncertainty due to use of different modeling techniques.

- Fifth, even if the casks were to tip over the record establishes that there would be no release of radioactive material. See Section IV.H, infra. Therefore, even if alleged uncertainties in Holtec's dynamic cask stability analyses somehow resulted in cask tipover, the public health and safety would still be adequately protected.

For these reasons, potential uncertainties in the dynamic cask stability analyses have been adequately considered and accounted for by using a wide range of input parameters and different modeling techniques as well. All these analyses show significant margins against cask tipover still remaining, even for the 10,000-year earthquake. Further, even if the casks were to tip over, no radioactive release would occur. Accordingly, formal quantification of uncertainty, as stated by Dr. Cornell, is unnecessary and the record clearly establishes that PFS has met its burden of showing sufficient conservatisms exist to meet a performance goal of 1 x 10^{-4}.[213]

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duce the uncertainty that would normally exist in a nuclear power plant seismic PRA. Tr. 8021-22 (Cornell).

[212] In addition, Holtec's analyses only accounted for impact damping between the cask and the pad and conservatively ignored all other damping. PFS F. ¶ 184.

[213] The State would also have the Board reject Dr. Cornell's opinion that the uncertainties arising from the soil structure interaction analysis for the PFS site would be comparable to uncertain-

R417. The State argues that "Holtec's conclusions that the canister would not be breached are dependent upon its assumption that the angular velocity of a tipping cask is zero." State F. ¶ 515. The State further claims that this is inconsistent with Dr. Cornell's testimony that "[t]he initial [angular] velocity [of the tipping cask] would probably clearly have to be something greater than zero or it would not be moving in that direction." Id., quoting Tr. 7978 (Cornell). The State is wrong in both assertions. First, as discussed above, the ductile stainless steel canisters have large inherent safety margins against actual failure that protect against breach even at impact forces significantly greater than those experienced in the hypothetical cask tipover analysis. See Section IV.F.9, supra. Therefore, there is no basis for suggesting that the canister would breach in the event of a cask tipover and no testimony indicating that they would. Second, Drs. Singh and Soler testified that the initial angular velocity of a tipping cask would likely be greater than zero, and thus their testimony is not inconsistent with Dr. Cornell's.[214]

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ties for an SSI analysis at a NPP (referenced by Dr. Cornell in discussing potential uncertainties in Holtec's cask stability analysis) because it is "[s]omewhat contradictory" to his admission that he is unaware of any NPP site which is supported by cement-treated soil and a layer of relatively soft soils such as at the PFSF site. State F. ¶ 517. However, as discussed in the response to a similar claim in State F. ¶ 533, infra, the record shows that soil cement and cement-treated soil are superior in terms of ability to withstand dynamic loadings than to structural fill that is otherwise used to replace unsatisfactory soil at a NPP. Moreover, the cask stability analyses that both Holtec and Sandia performed included analyses for the lower bound, best estimate and upper bound soil properties (which included the layer of cement treated soil and soil cement surrounding the casks). Singh/Soler Dir. at A33-A37 (use of upper and lower bound and best estimate for 2,000 year DBE); A113-A121 (use of lower bound soil properties and alternative worst case, unrealistic assumptions for 10,000 year beyond design analyses); Staff Exh P at 30-32. The purpose of using a range of properties is to account for not only potential variation in those properties but also uncertainties in the modeling of soil-structure interaction effects that are difficult to quantify. Young/Tseng Dir. at A19, A56. The results of the analyses do not show great sensitivity to the particular set of soil properties used in the analysis. Singh/Soler Dir. at A36; PFS Exh 86D; PFS Exh OO; Staff Exh P at 30-32.

[214] See Section IV.F.9, supra. As discussed above, the point made by Drs. Singh and Soler is that (1) the initial angular velocity of a tipping cask would be negligible because of the precessionary motion of the cask and (2) the effect of any such minimal increase in angular velocity

R418. The State next posits a confused finding that mixes the slope of the hazard curve, non-linear soil behavior, and the seismic scale factor used under the DOE-STD-1020 methodology. State F. ¶ 518. The State's proposed finding, goes beyond the scope of the testimony and expertise of the witness (Dr. Bartlett) on whose testimony the proposed finding rests, appears to disregard, that the hazard curve is a fundamental product of the PSHA with which the State has not taken issue, and mistakenly claims that PFS's analysis is faulty because it has not calculated the seismic scale factor "based on considerations of the slope of the hazard curve." Id.

R419. Regarding the first of these points, State claims that because "[t]he slope of the hazard curve for the PFS site may . . . be impacted by nonlinear soil behavior. NUREG/CR-6728 recommends that nonlinear soil effects on the determination of the seismic scale factor be included in the development of hazard curve slope," and that this "concept of accounting for nonlinear behavior is also applicable to any nonlinear behavior, such as cask sliding on the pad." State F. ¶ 518, citing "Bartlett Tstmy (Part E), Post Tr. 12776 at 12" – i.e., Bartlett Section E Dir. at A26. However, at the hearing, Dr. Bartlett admitted that whether this concern was in fact applicable to Holtec's beyond design basis analyses using the 10,000-year earthquake was outside his area of expertise. Tr. 12855 (Bartlett).

R420. In this respect, the specific point being asserted by Dr. Bartlett in his pre-filed testimony cited in State F. ¶ 518 was that, because of nonlinear effects, the performance of a structure at higher ground motions "cannot be extrapolated from [its] response at lower ground motions." Bartlett Dir. at A26; see also Tr. 12841-42,

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compared to the zero angular velocity assumed for the static hypothetical cask tipover analysis would likely be offset by the shorter distance that a precessionary cask would fall. Id.

12855-57 (Bartlett). However, the stability of the casks for the 10,000-year beyond design basis earthquake was not extrapolated from the casks' response for the 2,000-year DBE. Rather, Holtec used the actual ground motions for the 10,000-year event as well as the associated soil properties to evaluate the casks' stability. See PFS Exh 86C at 12, 17, and App. C, pg. C-1. At the hearing, Dr. Bartlett agreed that PFS did not extrapolate the results of the cask stability analysis for the 2,000-year earthquake to the 10,000-year earthquake. Tr. 12842, 12847-48 (Bartlett). When asked specifically whether Holtec's use of the 10,000-year ground motions and associated soil properties resolved the concern expressed in question and answer 26 of his pre-filed testimony, Dr. Bartlett stated that he could not say whether "this concern has disappeared in those analyses done by Holtec for the 10,000 year return period" because that fell into "Dr. Ostadan's area of expertise." Tr. 12855 (Bartlett). Dr. Bartlett did go on to say that "if Holtec properly accounted for the non-linear effects of the soils for the 10,000-year return period event, then I think this [concern] would disappear." Id. at 12857 (Bartlett).[215]

R421. While not clear because of its confused nature, State F. ¶ 518 also appears to claim that the hazard curve for the PFS site is deficient because it allegedly does not account for non-linear soil effects. The seismic hazard curve is, however, the final product of the PSHA that Geomatrix performed for the PFS site, and ac-

[215] In this respect, the record shows that Holtec used the lower bound soil properties developed by Geomatrix for those 10,000 year simulations for which it did not specifically pre-select the soil spring stiffness and radiation damping values. PFS Exh. 86C at ~~—~~ 15-16 and App. C, pg C-1. Dr. Ostadan testified that Geomatrix used standard procedures in developing the soil properties used in the various Holtec and other PFS analyses and stated that no issues existed with respect to Geomatrix's development of soil properties. Tr. 7514-15, 7574 (Ostadan). Further, how Holtec incorporated these soil properties into its 10,000 year beyond design basis analysis is set forth in Appendix C to the Holtec Beyond Design Basis report. PFS Exh. 86C at App. C. No challenges have been raised by the State to those calculations.

counts for site-specific soil conditions. See Tr. 5840-42 (McCann); Young/Tseng Dir. at A12. The State has stated that it has no issue with the adequacy of the PSHA that Geomatrix performed for the PFS site. Indeed, the State's PSHA expert, Dr. Arabasz, repeatedly refers to the hazard curve for the PFS site in his testimony without suggesting that it is erroneous in any respect. See, e.g., State Exh. 205; Tr. 10112-13 (Arabasz). Therefore, any attacks on the PFS hazard curve are contrary to the testimony of all witnesses and out of the scope of this hearing, since they have never been previously raised by the State in Contention L/QQ.

R422. State F. ¶ 518 also claims that PFS has not "calculated the seismic scale factor based on considerations of the slope of the hazard curve." The seismic scale factor is used in the DOE-1020 methodology to achieve the desired risk reduction ratio for the design acceptance criteria appropriate for the corresponding target performance goal and the associated DBE MAPE. Cornell Dir. at A29 & Attachment A at 2-3. As the State recognizes, the DOE-1020 methodology is only illustrative and not applicable here. See State F. ¶ 505. PFS did not rely upon the DOE methodology to determine the appropriate design criteria or to calculate the applicable risk reduction ratios. Rather, as set forth in Attachment A to Dr. Cornell's testimony, PFS relied upon the results of the seismic PRAs and seismic margin studies that have been done for virtually every NPP in the US to calculate the risk reduction factors applicable for typical NPP SSCs. Cornell Dir. Attachment A at 3-4. Further, because the applicable risk reduction factors are dependent on the slope of the hazard curve, PFS chose the applicable risk reduction ratios for the PFS site based on the slope of the hazard curve for the PFSF site. Cornell Dir. Attachment

A at 4.[216] Thus, contrary to the State's claim, PFS did compute the applicable risk reduction ratios for the PFSF "based on considerations of the slope of the hazard curve." For all these reasons, State F. ¶ 518 is totally erroneous.

R423. The State requests that the Board give "no weight" to Dr. Cornell's opinion that "['g]iven the decades of NRC's concern about seismic safety, and given the codes, standards and criteria they call for, one would expect *a priori* similar levels of conservatism in any SSC designed to their SRPs, ~~"[sic]~~ [and] a similar range of risk reduction ratios. Cornell Tstmy, Post Tr. 7856 at 35 (emphasis added)." State F. ¶ 519. The basis for the State's request is "Dr. Cornell's unsupported supposition that NRC would employ 'similar levels of conservatism' resulting in a similar range of risk reduction ratios" in any SSC designed to the NRC SRPs. Id. (emphasis added). For SSCs typical of NPPs, it can be shown that risk reduction factors of 5 to 20 or more are appropriate based on the seismic PRAs and seismic margin studies performed for U.S. NPPs. Cornell Dir. at Attachment A. In the testimony cited by the State, Dr. Cornell opined that is logical to presume that for SSCs designed to the NRC SRPs other than SSCs typical of NPPs, one would also expect a priori similar levels of design conservatism, but that one would need to conduct confirmatory analysis to confirm the existence of similar risk reduction ratios. Cornell Dir. at A62; see also id. at A33; Cornell Reb. at A3. The Holtec and Sandia cask stability evaluations for the 10,000-year earthquake constitute such confirmatory studies and provide a sound technical basis on which to conclude that the casks achieve a performance goal of at least 1 x 10^{-4}. Cornell Dir. at A52. There is no "unsupported supposition" in Dr. Cornell's testimony.

[216] Further, as just discussed, PFS evaluated the stability of the casks directly using the 10,000-year ground motions and the associated soil properties from which one could determine risk reduction factors of at least 5 for the casks. Cornell Dir. at A.52.

(4) Transfer Operations in the CTB

R424. The State challenges Dr. Cornell's determination of the appropriate risk reduction factors applicable for the CTB and the seismic struts and cranes inside the CTB because it disagrees with "the time in which the canister is potentially exposed and SSCs are in use during transfer at the PFS site" and the validity of the specific CTB conservatisms set out in Mr. Ebbeson's testimony relied upon by Dr. Cornell. State F. ¶¶ 522-24. These challenges, however, totally ignore the primary rationale for Dr. Cornell's conclusion on the risk reduction factors applicable to the CTB. Dr. Cornell testified:

> The Canister Transfer Building itself and the cranes and seismic struts inside the building are typical of nuclear power plant components for which the risk reduction factor has been shown to be a factor of 5 to 20 or more. That basis alone would be sufficient to conclude that the CTB and the cranes and seismic struts inside the CTB have a risk reduction factor of five or more.

Cornell Dir. at A48; see also id. at A40.[217] None of the State's experts took issue with the appropriateness of using a risk reduction of 5 to 20 or more for the CTB and the cranes and struts therein. See Tr. 9132 (Arabasz); Tr. 12786, 12814 (Bartlett).

R425. Unlike its experts, the State's findings challenge the use of a risk reduction of 5 to 20 or more for the CTB and the cranes and struts therein, focusing on the two ancillary supporting reasons for the determination. The State claims "there are serious shortcomings" in PFS' estimation of the time during which the canister is potentially exposed and the SSCs are in use during the transfer operations between

[217] As explained by Dr. Cornell, the same (or very similar) SSCs in the NPPs have been analyzed in the many seismic PRAs and margins studies that provide the experience base upon which the general range of R_R values of 5 to 20 or more is based. Id. at A40.

the storage and transportation casks. State F. ¶¶ 522, 524. As discussed in Section IV.C.2 above, the time durations estimated by PFS for various aspects of the transfer operation are reasonable. In addition, and most importantly, the reduction in risk obtained by virtue of the intermittent use of the crane and seismic struts is an <u>additional</u> reduction of the risk above and beyond the risk reduction ratio of 5 to 20 or more that otherwise would apply to these SSCs. Cornell Dir. at A49 ("the effect of the 20% use fraction is, in effect, to increase R_R by a factor of 5"). Therefore, any shortcomings in the PFS estimations of percentage use of SCCs in the CTB would be immaterial. Even if the SSCs were assumed to be constantly in use, their applicable risk reduction ratio would still be 5 to 20 or more.

R426. The State also notes Dr. Cornell's reference to "the beyond-design-basis analyses and margins described in the testimony of Mr. Ebbeson" which "confirm the existence of significant beyond-design-basis margins in the design of the CTB and the cranes and struts therein, which would enable them to survive earthquake ground motions much greater than those of the 2,000-year design basis earthquake." State F. ¶ 523 (quoting Cornell Dir. at A49). The State, however, refers specifically to the design basis calculation for the seismic struts, completely ignoring the uncontradicted evidence in the record of the large conservatisms embodied in the design basis for the struts. Ebbeson Dir. at A15, A20; Tr. 8025-27 (Cornell). The State then claims that the "only <u>engineering design calculations</u> to support the PFS license are for a 2,000 year DBE," and posits the following proposed finding:

> "Given the foregoing, the <u>Board is unwilling to accept such a cutting edge probabilistic approach to seismic performance</u>."

State F. ¶ 524 (emphasis added). This proposed finding reflects a complete disregard for the evidentiary record in the proceeding. Not only does the State ignore the uncontradicted testimony of PFS's experts, it even disregards the testimony of its own experts.

R427. First, despite the small margin shown in the design calculation between the maximum load of 395 kips on the seismic struts for the 2,000-year DBE and the code allowable stress of 400 kips, there are in fact very large beyond-design-basis margins that would enable the struts to survive earthquake ground motions much greater than those of the 2,000-year DBE. As an initial matter, the uncontradicted evidence is that "ultimate strut load capacity is at least 571 kips." Ebbeson Dir. at A20; see also id. at A15. Although this ultimate load capacity or static ultimate strength of the struts is significantly greater than the code allowable stress of 400 kips, it constitutes only a fraction of the design margin available to resist earthquake loads. Tr. 8025-27 (Cornell); see also Ebbeson Dir. at A15. The "very much" larger margin results from the cyclic nature of an earthquake which reverses direction several times each second. Tr. 8026-27 (Cornell). The cyclic nature of earthquake loadings causes the deformation of a ductile component, like the struts, to reverse and return to the elastic range before significant distortion occurs. Id.; see also Ebbeson at A15. These excursions in and out of the linear and nonlinear regimes enable a ductile structure or component to withstand "very large deformations" before failing. Id. Thus, the small difference between the design calculation stress and the code allowable stress is totally irrelevant to the true capacity of the struts.

R428. Second, as already stated, the State completely fails to pay the slightest attention to the conservatisms in the codes and the attendant large margins against failure inherent in components, like struts, designed against those codes. Instead, the State focuses solely on the engineering design calculation for the seismic struts and, in effect, argues that this Board should ignore any beyond-design-basis margins because the "only engineering design calculations to support the PFS license are for a 2,000 year DBE." State F. ¶ 524.

R429. In making this argument, the State completely ignores the hours of hearing testimony regarding the "two-handed approach" to seismic design margins, which was "emphatically" endorsed by the State's experts. PFS F. 423, Tr. 12809 (Bartlett) ("We have to use a two-handed approach."). At the heart of the two-handed approach is the concept of giving due account to the beyond-design-basis margins embedded in the code acceptance criteria. Tr. *** 9121, 10048, 10150 (Arabasz), Tr. *** 12808 (Bartlett) Tr., *** 12961-62 (Cornell). Both Dr. Arabasz and Dr. Bartlett expressed great concern about the asserted use of a one-handed approach by the Staff, and initially by the Applicant, for evaluating the exemption "neglecting to discuss the inherent conservatisms that must be there to meet a performance goal." Tr. 12808 (Bartlett); <u>see also</u> Tr. 9134, 10147 (Arabasz). The State would now have the Board erase all this testimony by the State's own witnesses (as well as by Dr. Cornell and other PFS witnesses) and dismiss it as "<u>cutting edge probabilistic approach to seismic performance</u>," State F. ¶ 524 (emphasis added).

R430. <u>Finally</u>, because the two-handed approach looks to the inherent beyond-design-basis margins embedded in the design acceptance criteria, the fact that the "<u>only</u> engineering design calculations to support the PFS license are for a 2,000 year DBE," State F. ¶ 524 (emphasis added), is irrelevant. Indeed, the two-handed approach is based on examining the true capacity of structures to perform safely beyond their normal design limits. Therefore, to require an "engineering design calculation" to support a showing of beyond-design-basis margins is an oxymoron. Rather, the intent in evaluating beyond-design-basis margins is to "strip away" any conservatisms embedded in the design acceptance criteria to check the actual conditions under which component failure would occur. Tr. 12954 (Cornell); see also Cornell Dir. at A61.

(5) CTB and Storage Pad Foundations

R431. The State again claims that "Dr. Cornell's opinion" of risk reduction ratios of 5 or greater for the CTB and storage pad foundations "must be tempered with the [State's proposed] finding that there are no engineering calculations to support PFS's supposition that its facility can withstand a 10,000-year DBE." State F. ¶ 526. The finding repeats the erroneous argument advanced in State F. ¶ 524 and should be dismissed for the same reason.

R432. In this proposed finding, however, the State goes one step further than in State F. ¶ 524, saying: "[i]f such were the case, the Board sees no reason why PFS should be applying to the NRC for an exemption from the deterministic ground motions requirements," which for the PFS site are in the same range as those for the 10,000-year earthquake event. Id.

R433. Precisely this question was asked by the Board and fully explained at the hearing. Designing a structure in conformance with the NRC's SRP design acceptance criteria is entirely different than evaluating the margins embedded in the design acceptance criteria called for by the two-handed approach endorsed by both the State's and the Applicant's experts. In designing for a 10,000 year earthquake the applicant would need to establish that its design meets the SRP acceptance criteria for the 10,000-year ground motions. In so doing, the Applicant would be in effect redesigning the facility so that it can withstand much higher earthquake acceleration, i.e. those from an earthquake with a return period much longer than 10,000-years. See Tr. 12963-66 (Cornell). The State's logic would then require the Applicant to design its facility to this much larger earthquake, creating a proverbial "catch 22" situation.

R434. The State similarly claims that PFS has "has not performed any foundation stability calculations for a 10,000-year mean return period earthquake and has not shown that the foundations meet a factor of safety of 1.1 for that case." State F. ¶ 528. Again, to require the performance of design calculations showing of a factor of safety of 1.1 against sliding for the 10,000-year earthquake would be to impose the SRP design acceptance criteria for the 10,000-year earthquake which, as explained above, is contrary to the purpose of evaluating the beyond-design basis margins to determine under what conditions failure would occur. Tr. 12954 (Cornell). One could do a beyond-design-basis calculation for the foundations analogous to the Holtec Beyond Design Basis Report for the casks. However, such is not necessary for the foundations. Id. at 12954-56. PFS has quantified some of the major conservatisms that exist with respect to the storage pad and CTB foundations and has shown by this quantification that there are factors of safety inherent in the design of the foundations that would allow them to withstand loads from the 10,000-year earthquake. Id.; see also Cornell Dir. at A50-A51; PFS F. 438-444.[218]

R435. The State has referred to the nonlinear properties of the soil under dynamic loading and has argued that one cannot extrapolate the sufficiency of a design to withstand failure at 10,000-year earthquake levels based on analyses done for the 2,000-year earthquake without performing a formal calculation. See State F. ¶

[218] The one exception is that the margins against sliding of the CTB are not as large so as to preclude sliding under 10,000-year earthquake conditions, but as already discussed, no negative safety consequences would result from sliding of the CTB. Tr. 7323-24 (Bartlett/Ostadan); Ebbeson Dir. at A18, A25; Cornell Dir. at A50.

~~528~~ 518. However, if anything, soil nonlinearities would result in less than proportional increases in the earthquake load on a structure. Tr. 12955-56 (Cornell). In this respect, it is undisputed that there would be higher levels of radiation damping of the soil associated with the higher strain levels of the soil under the larger earthquake loads. Id.; see also Tr. 12848 (Bartlett); Ebbeson Dir. at A18. Dr. Bartlett did not identify any nonlinear soil property that would offset the less than proportional increase in demand due to the higher effects of damping.

R436. The State asserts that no credence should be given to Dr. Cornell's opinion that the CTB and storage pad foundations have risk reduction ratios of 5 or greater because "without reviewing the details, Dr. Cornell relies on the analyses of Mr. Trudeau and Mr. Ebbeson." State F. ¶ 530. However, as discussed above, an expert can rely on information provided by other experts. There is particularly no reason not to allow such reliance here where the State was free to cross-examine Mr. Trudeau and Mr. Ebbeson on any of the conservatisms that they identified in their testimony upon which Dr. Cornell relied.[219] Moreover, Dr. Cornell testified that he reviewed and discussed with Mr. Trudeau the assumptions concerning the various conservatisms embodied in Mr. Trudeau's calculations for the storage pad and CTB foundations set forth in his pre-filed testimony. Tr. 7990-91 (Cornell).

R437. The State also claims that "Dr. Cornell, relying on other PFS witnesses, admitted there would be sliding of the storage pads for a 10,000-year mean return period earthquake. Cornell Tstmy, Post Tr. 7856 at 28." State F. ¶ 528. The State, however, misreads Dr. Cornell's testimony, which states as follows with respect to potential sliding of the pads.

[219] Dr. Cornell testified that analyses and assessments of Mr. Trudeau and Mr. Ebbeson that he relied upon were set forth in their respective pre-filed testimonies. Tr. 7989-91 (Cornell).

> Also, as PFS witnesses confirm, sliding of the storage pads is not expected, per se, to cause hazardous material release. The effect of any such pad sliding on the behavior of the storage casks has been considered in the assessment of the cask.

Cornell Dir. at A51. Thus, Dr. Cornell did not testify that there "would be sliding of the storage pads" for the 10,000-year earthquake as claimed by State. Rather, his testimony is that the sliding of the pads, if it were to occur, would have no adverse safety consequences. See, e.g., Section IV.D.4 above. Therefore, sliding of the pads is irrelevant to whether the storage pads and the PFSF facility achieve a performance objective of 1 x 10^{-4}.[220]

R438. As it did in State F. ¶ 519, the State would reject Dr. Cornell's opinion that because of "NRC's long concern over seismic safety margins there is *a priori* reason to expect similar risk reduction ratios for the CTB foundation to those of NPPs. State F. ¶ 529. However, the NPP seismic PRAs and margin studies on which a risk reduction of 5 to 20 or more is based included potential foundation failure modes such as overturning, bearing, and sliding. Tr. 12953 (Cornell). Thus, these NPP seismic PRAs and margin studies support the use of a risk reduction factor for potential foundation failure modes "at least as large" as the 5 to 20 risk reduction factor applicable for structural and mechanical failure modes. Id. This provides a wholly separate basis, apart from specific conservatisms identified in Mr. Trudeau and Mr. Ebbeson's testimony, for Dr. Cornell's confidence that risk reduction ratios of 5 to 20 or more apply to foundations. Tr. 7991 (Cornell); Cornell Dir. at A41, A 50.

[220] Nevertheless, "exceptionally conservative" assumptions also protect the pads against sliding in a beyond design basis earthquake. PFS F. ¶¶ 438-39.

R439. The State also challenges Dr. Cornell's reliance on these NPP seismic PRAs and margin studies, because none of the NPPs evaluated were supported by cement-treated soil or soil cement, nor could Dr. Cornell identify an NPP site supported by soil cement and relatively soft soils. State F. ¶ 533. The State's challenge fails. The record shows that soil cement and cement-treated soil are superior in terms of ability to withstand dynamic loadings than to structural fill that is otherwise used to replace unsatisfactory soil at a NPP. Tr. 10839-40; 10848-49; 10972-73, 11237-38 (Trudeau). Nor has the State suggested any way that the soil cement, cement-treated soil or the relatively soft soils at the PFSF would adversely affect the foundations other than the specific issues already discussed with respect to the use of soil cement and cement-treated soil. See Section IV.B above.

(6) Evidence that Risk Reduction Ratios for ISFSIs are "Similar" to those for NPPs

R440. The State does not directly challenge Dr. Cornell's conclusion that "typical" NPP SSCs have a risk reduction factor in the range of 5 to 20 or greater. See State F. ¶¶ 531-538. Rather, the State raises a series of indirect challenges seeking either to limit the scope or negate the applicability of that conclusion. They are without merit.

R441. The State notes as an initial matter that Dr. Cornell acknowledges that the NRC's seismic SRPs "are not explicitly keyed" to risk reduction ratios. State F. ¶ 531. The fact, however, that the NRC has not explicitly tied the inherent conservatisms of its well-established defense in depth policy to specific risk reduction values (as DOE has) does not mean that such conservatisms do not exist, as the State would imply. The evidence in the record clearly establishes the existence of risk reductions of 5 to 20 or more for typical NPP SSCs. Cornell Dir. at Att. A; Cornell Reb. at A3; see also Tr. 9149-50 (Arabasz); Tr. **** 12814 (Bartlett).[221]

R442. The State challenges Dr. Cornell's statement that "NRC SRPs contain many conservatisms that result in risk reduction factors as large as, or larger than, those for PC4 category facilities designed to DOE-STD-1020-94." State F. ¶ 534, quoting Cornell Dir. at A30 (emphasis added by State) The State correctly notes that Dr. Cornell "relies, in part, on NUREG/CR-6728 to support this statement" and then asserts, without citing any basis, that:

> NUREG/CR-6728 has quantified levels of risk reduction ratios in the range of 5 to 20 for certain NPP SSCs whereas in DOE Standard 1020 NPP SRPs have risk reduction ratios in the range of 10 to 20. The Board finds that the reverse is true – that DOE-STD-1020 has greater risk reduction factors than does NUREG/CR-6728.

Id. This proposed finding is completely erroneous. Not only does it ignore DOE's own statement that the DOE's "[c]riteria for PC4" SSCs only "approach the provisions for commercial nuclear power plants,"[222] but it totally misconstrues the record.

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[221] The State next asserts that "[n]o other party supports Applicant's 'similarity argument'," that the risk reduction ratios for ISFSIs are similar to those for typical NPP SSCs. State F. ¶ 531. The State, however, fails to explain the relevance of this assertion, and we see none. None of the parties' witnesses disputed Dr. Cornell's conclusion that typical NPP SSCs have risk reduction ratios of 5 to 20 or more or the appropriateness of applying those risk reduction ratio to analogous PFS structures and components, such as the CTB and the struts and crane therein. Cornell Dir. at A31, A40, A48. In this respect, the Staff fully recognizes that the conservatisms embodied in the NRC's seismic design requirements provide a level of safety beyond the MAPE of the DBE. See Stamatakos/Chen/McCann Dir. at A25, A31; Tr. 12716-17 (Stamatakos). Further, Dr. Arabasz acknowledged that "Dr. Cornell is a recognized expert in [the] area of evaluating conservatisms that exist in codes and standards" and often referred to Dr. Cornell's testimony as an authoritative source. Tr. 9180, 10146, 10159-62, 10213 (Arabasz).

[222] PFS Exh. DDD (DOE-STD-1020-94, p. 2-2, C-4 to C5).

R443. At the outset, the State is wrong in claiming that the quantification of the risk reduction of 5 to 20 or more for typical NPP SSCs comes directly from NUREG/CR-6728. To the contrary, the quantification of this number is set forth in Attachment A to Dr. Cornell's testimony. There, Dr. Cornell calculates the actual risk reduction ratios for both DOE PC4 facilities, using the applicable inputs from DOE-1020, and for typical NPP SSCs, using applicable inputs from NUREG/CR-6728. For DOE PC4 SSCs, the calculated range of risk reduction ratios is 8 to 17 and for NPP SSCs the calculated range is 8-32. Cornell Dir., Att. A at 3-4. Thus, the comparison demonstrates that risk reduction ratios for DOE-1020 PC4 SSCs only "approach" those of commercial NPP, as DOE-1020 itself states, and that, directly contrary to the States posited finding, NPP SSCs possess greater risk reduction ratios than do SSCs designed to DOE category PC4 criteria.[223] Likewise, the State's other assertions based on its erroneous perception of the comparative margins of DOE 1020 PC4 criteria and NRC SRPs are without merit.[224]

R444. The State suggests findings that "[c]ompared to the original deterministic standard, the 2000-year DBE . . . reduces the safety level achieved" and that

[223] After calculating the range of risk reduction ratios for typical SSCs at NPPs generally for a range of hazard curve slopes, Dr. Cornell adjusted the values to the slope of the hazard curve for the PFS site and arrived at ranges of 12-21 and 8-12 for different spectral accelerations. Cornell Dir., Att. A at 4. "For simplicity," he summarized his results as showing that "the R_R's for typical SSCs designed to the NRC SRP are in the range of 5 to 20 or greater." Id.

[224] The State asserts in this respect that "Dr. Cornell does not address under his 'similarity argument' whether and how NUREG/CR-6728 calculations of some risk reduction ratios below that required by DOE Standard 1020 would result in risk reduction ratios of 5 for PC3 facilities." State F. ¶ 534. As explained above, the premise for this assertion, that NUREG/CR-6728 calculates some risk reduction ratios below that required by DOE Standard 1020, is wholly erroneous. Moreover, wholly apart from its erroneous premise, the assertion is contradicted by the fact that the lower bound of Dr. Cornell's range of risk reduction ratios for typical NPP SSCs is 5, the same as that required for PC3 facilities under DOE 1020-94 based on a 2,000-year DBE. See Cornell Dir. at A27, Table 1.

"[a]lthough the factor of safety is the same for both earthquakes, the actual capacity – the design margin – is larger for the 10,000-year earthquake compared to the 2,000-year earthquake." It requests the Board to find that "PFS's 2,000-year DBE design does not have the same design margin as a 10,000-year DBE design for a NPP." State F. ¶¶ 535-36.

R445. The State fails to explain the relevance of these two proposed findings to the issues regarding the seismic exemption request, and we see none. The question before the Board is whether the 2,000-year DBE adequately protects the public health and safety. Under the two-handed probabilistic risk approach proposed by PFS and endorsed by the State's experts, this ultimate question turns on whether the design meets an appropriate performance goal, which the State and the Applicant agree is 1 x 10^{-4}. The safety factor (the ratio between capacity and demand) and the risk reduction ratio (the ratio between the DBE MAPE and the performance goal) are both measures of the second hand of the two-handed approach and provide the same improvement in safety regardless of the design basis level. Tr. 7916-17 (Cornell); <u>see also</u> note 225 <u>infra</u>. The safety margin itself is the difference between capacity and the DBE, and is not a fixed, absolute number. Tr. 7914 (Cornell). Therefore, the State's posited findings appear to be yet another attempt to avoid the logic of the two-handed approach endorsed by its witnesses.

R446. The State next attempts to find an inconsistency between Dr. Cornell's opinion that typical NPP SCCs have risk reduction ratios of 5 to 20 or greater and "his other testimony that the margins are 2 to 3 times the design basis capacity." State F. ¶ 537, citing Tr. 7916-17 (Cornell). The record shows nothing of the sort. Judge Lam had referred to a "safety factor" of 2 to 3 for reactor containment design pressures in asking about the relative conservatisms of Part 100 Appendix A requirements and the proposed 2,000-year DBE. Dr. Cornell's answer used the same 2 to 3 safety factor in explaining that the relative degree of margin would be the same using either Part 100 Appendix A or the proposed 2,000-year DBE. As the State itself notes, a factor of safety is a function of the capacity of the structure divided by the earthquake load. State F. ¶ 536. Therefore, a safety factor of 2 for the PFSF DBE of 0.71g would mean that it could withstand earthquake loads twice that of the DBE, or up to 1.42g. Thus, a safety factor is different from a risk reduction ratio, which is probabilistic reduction in risk.[225] Indeed, on the very next page, Dr. Cornell refers to a probabilistic reduction in risk of 5 or more in discussing the conservatisms embodied in the proposed 2000-year DBE. Tr. 7918 (Cornell). Thus, contrary to the State's claim, there is no inconsistency in Dr. Cornell's testimony.

R447. The last proposed finding of this section does not challenge the conclusion that the risk reduction ratios for SSCs at the PFSF are five or more. State F. ¶ 538. Rather, the State claims that "Applicant implies, albeit not directly, that a risk reduction ratio of 5 provides an adequate safety margin because DOE mandates at least a risk reduction ratio of five for performance category 3 facilities, and NPPs have risk reduction ratios of five or greater." Id. citing Cornell Dir. at 18-19. The State, however, references the wrong pages of Dr. Cornell's testimony for his rationale why the 2,000-year DBE for the PFSF provides adequate safety margin. The pages the State cites are from the portion of his testimony that describes the general principles of risk informed regulation where he discusses and compares

[225] Attachment A to Dr. Cornell's prefiled testimony sets forth the mathematical relationship between the risk reduction ratio, R_R, and safety factors or margins in the design. The risk reduction ratio is related to the safety factor by a power equal to the slope of the hazard curve. See Cornell Dir. at Att. A, Eqn. 2. This same equation shows the risk reduction ratio to be independent of the DBE or the design basis ground motion levels.

the general conservations embodied in DOE and NRC standards, whereas his testimony at 29-31 directly sets forth the reasons why the 2,000-year DBE for the PFSF, coupled with demonstrated risk reduction factors for the PFSF of 5 or more, provides an adequate level of safety. Cornell Dir. at A54, A55. Dr. Cornell clearly states his rationale and it is not necessary to imply or infer it from the general background discussion in his testimony. Id.; see also PFS F. 426.

d) State's Proposed Board Findings

R448. In proposing concluding findings for the Board on establishing a risk graded design basis earthquake for the PFSF (State F. ¶¶ 539-43), the State continues to ignore the evidence in the record, much of it provided by its own witnesses. The State asserts that "[t]he Applicant cannot claim that PFS's design meets the performance goal and risk reduction factors in DOE-STD-1020 yet also claim it does not rely on DOE-STD-1020 so it does not have to follow its design philosophy and standards." State F. ¶ 539; see also State F. ¶ 538. There is no truth to the State's charge that PFS is trying "to have it both ways" with respect to the DOE-STD-1020. State F. ¶ 539. In reality, both the Applicant's and the State's witnesses agreed that DOE-STD-1020 is not applicable to the PFSF but is merely illustrative of the two-handed approach. See Cornell Dir. at A85, 87; Tr. 9127 (Arabasz). Moreover, PFS does not claim that the exemption is appropriate because it meets DOE-STD-1020 standards. PFS has fully and appropriately justified its risk reduction factors outside of the DOE-STD-1020 context and has shown why a performance goal of 1×10^{-4} is appropriate under the Commission's risk graded probabilistic approach and risk graded principles generally. In that context it has referred to the performance goal for PC3 facilities under DOE-STD-1020 as support for why 1×10^{-4} ~~for the PFSF~~ is an appropriate performance goal for the PFSF. Cornell Dir. at A55; see also PFS F. ¶ 426. The State's experts fully agree that a performance goal of $1x10^{-4}$ is an appropriate choice here. Tr. 10154-55 (Arabasz); Tr. 12832 (Bartlett).

R449. The State similarly claims that "absent a regulatory framework which establishes performance goals and risk reduction ratios, the . . . conservatism in the PFS seismic design for a 2,000-year DBE cannot be measured." State F. ¶ 540. The State's assertion is in a word wrong.[226] The numerous seismic PRAs and margin studies have measured the conservatism that is generally achieved under the NRC's regulatory framework. Cornell Dir. at Att. A; Cornell Reb. at A3. Further, PFS as well as the NRC Staff have provided additional, PFS-specific information demonstrating the conservatisms achieved by the PFSF design, particularly with respect to the casks' ability to remain stable and not tip-over even under 10,000-year earthquake ground motions. PFS has demonstrated sufficient conservatisms in its design of the PFSF to achieve performance goal of $1x10^{-4}$. The State's proposed finding to the contrary must be rejected.

R450. In sum, in its proposed findings, State in one voice argues for the use of a risk graded two-handed approach analogous to DOE-STD-1020, but in another seeks to disavow the logical results flowing from its application. In this respect, Dr. Arabasz fully agreed that if the conservatisms discussed in Dr. Cornell's testimony, resulting in risk reduction ratios of 5 or more, were shown to exist, then it would be established that a performance goal of $1x10^{-4}$ has been met. Tr. 9129-

[226] Paradoxically, earlier the State had argued that to "reasonably assure" public health and safety, the DBE for the PFSF "must be formally linked to a specific performance goal and risk reduction ratio." State F. ¶ 506. Now it claims that cannot be accomplished in the NRC's regulatory framework.

34, 9179-81, 10154-55 (Arabasz); see also id. at 10146-48 (Arabasz).[227] Unlike the State's proposed findings, Dr. Arabasz answered, "yes. That's where the logic train takes me and I have committed to that." Id. at 10154.

5. Annual or Lifetime Risk

R451. In its proposed findings dealing with the duration of the seismic risk to be assumed in selecting an appropriate DBE for the PFSF, the State levels as a criticism that "Dr. Cornell has proposed an approach that is based strictly on annual risk. . . ." State F. ¶ 585. In virtually all areas of public safety, however, the hazard is measured in terms of frequency of occurrence (typically annual frequency) and the same safety criteria are specified regardless of the length of the activity in question. Cornell Dir. at A94; Cornell Reb. at A1-A2. The NRC in its regulatory framework assesses risk on an annual basis. Id. So does DOE. Tr. 10170 (Arabasz). Thus, the use of annual frequency risk metrics is more than a mere "proposal" by Dr. Cornell. It is the standard and accepted method for assessing risk.

R452. The State suggests that use of a lifetime risk metric is appropriate here, however, because (1) the facility here has an expected operational life of 40 years, and the cumulative fatality risk of an individual living next to the facility for 40 years would be greater than one doing so for 20 years; (2) the decision is being made in the context of an exemption; and (3) the public interest should be brought into the decision-making process as the Uniform Building Code allegedly does by considering the exposure period. State F. ¶ 585. However, whether the proposed life of the PFSF is 40 years, 20 years or 10 years should not affect the risk metric for de-

[227] Dr. Arabasz predicated his agreement to this proposition on such a showing being made in the context of the "DOE paradigm." Tr. 9134 (Arabasz). By the DOE paradigm he meant "considering a seismic performance goal, a [seismic] hazard probability" and "the conservatisms achieved in the design procedures and acceptance criteria," or in other words the two-handed approach. Tr. 10147 (Arabasz); see also id. 9120-21, 9179-81 (Arabasz).

termining the appropriate level of seismic design. The level of risk should be determined on a consistent basis regardless of how long a person may live next to a site that stores spent fuel. Tr. 8004-06 (Cornell); see also PFS F. ¶¶ 490, 495. The only way to have risk-consistent decision-making, a Commission goal, is to utilize annual frequency risk metrics. Id. Indeed, in the context of a risk-based approach, Dr. Arabasz indicated that the use of an annual based frequency method was preferable. Tr. 10170 (Arabasz); see also Cornell Reb. at A2.

R453. There is no relevance to the fact that this decision is made in the context of an exemption. Under Appendix A of 10 C.F.R. Part 100, the same design basis earthquake would apply regardless of the lifetime of the facility or how long someone may live next to it. Likewise, the State's assertion that the UBC considers the exposure period in setting an appropriate design earthquake is wrong. The UBC results in the same frequency of exceedance being applied for seismic design regardless of whether a building is constructed for a 10 year lifetime, a 100 year lifetime, or any other lifetime. Cornell Reb. at A1; see also Tr. 8004-06 (Cornell); Tr. 9197-98 (Arabasz). It simply chooses to measure frequency in units of 50 years rather than a single year. Cornell Reb. at A1.

R454. Finally, the State requests that the DBE for the PFSF be set at a minimum of a 4,000-year mean return period earthquake, based an Dr. Arabasz's testimony. State F. ¶ 585, citing Tr. at 10152-53 (Arabasz). Dr. Arabasz's testimony does not support the State's proposed finding. The testimony cited by the State occurred as Dr. Arabasz was explaining the rationale for his answer to an earlier hypothetical question from the Board in which he had been asked to choose a DBE earthquake for the PFSF setting aside any consideration of the conservatisms in the design. Tr. 10150-54 (Arabasz); see also 9206-09 (Arabasz). Dr. Arabasz was "very reluctant" to do so because he was being asked to select a design earthquake without considering the second hand (design conservatism) of the two-handed approach, which he believes "emphatically" to be the appropriate approach to apply here. Id. at 10150; see also 9120-21, 9206-09, 10048 (Arabasz). Indeed, immediately following the pages the State cites, Dr. Arabasz agrees that if Dr. Cornell were correct that the PFSF design provides a risk reduction factor on the order of 5, "that would justify in [Dr. Arabasz's] mind the 2,000-year" DBE for the PFSF. Tr. at 10154-55 (Arabasz). Since the conservatisms described in Dr. Cornell's testimony do provide a risk reduction factor on the order of 5, there is no dispute that the 2,000-year DBE for the PFSF is appropriate and justified.

H. Section E of Contention L/QQ: Radiation Dose Consequences of Seismic Event

1. Background Discussion

R455. The State prefaces its findings on radiological dose consequences with the assertion that PFS has to show through site-specific analysis that "unanchored HI-STORM 100 casks would 'reasonably maintain confinement of radioactive material' under off-normal and credible accident conditions at the proposed PFS site, as required by 10 C.F.R. § 72.236" in order for an exemption to be granted. State F. ¶ 230. The State then raises the issue whether, "[i]n particular, assuming that the casks are tipped over during an earthquake at the PFS site, has PFS satisfied its burden of demonstrating that the radiation levels emitted from the casks will not exceed regulatory limits?" State F. ¶ 230. The State thereby seeks to require that PFS conduct an analysis of radiological dose consequences based on (1) presupposing a tip over of storage casks, even if such an event is not credible, and (2) conflating loss of confinement with a possible increase in radiological dose levels. As discussed in Section ~~IV.E~~ IV.F, the uncontested evidence shows that the storage casks will not tip over in a 2,000-year return period DBE, or even in a beyond-design basis 10,000 year return period earthquake. Moreover, as will be seen below, there will not be an increase in radiation levels at the site boundary even under a postulated, non-mechanistic cask tipover event.

a) Site Specific Analysis of Radiological Dose Consequences

(1) Introduction

R456. The State acknowledges that Dr. Redmond conducted a site-specific analysis to demonstrate that the PFSF would comply with the normal operation dose requirements of 10 C.F.R. § 72.104(a), based on a 2,000 hour/year occupancy factor. State F. ¶¶ 544-547.[228] The State, however, asserts that "Dr. Redmond did not conduct an analysis specific to PFS's exemption request and has not reviewed same." State F. ¶ 548. The State asserts that PFS did not conduct an analysis specific to the PFS exemption request, but rather relies on an extrapolation from the normal operational dose calculations that use a 2,000-hour year. Id. The State does not allege that there is anything intrinsically wrong with extrapolating from normal operational dose consequences to an accident analysis. The State would apparently require not only a site-specific analysis to determine whether there

[228] The State attempts to impeach the credibility of Dr. Redmond's testimony by stating that "Dr. Redmond testified that he had not visited the site, and did not know of present or future land use around the site." State F. ¶547. However, there is no testimony or other evidence suggesting that a visit to the site is necessary in order to perform a site-specific dose analysis. Also, Dr. Redmond's assumptions that the nearest resident is two and a half miles away from the site boundary and that the land beyond the owner-controlled area ("OCA") boundary is unoccupied and likely to remain so is borne out, *inter alia*, by the testimony of the PFS project manager Mr. Donnell, who is thoroughly knowledgeable of land uses around the PFSF. Tr. 12561-65, 12571-72, 12578-79 (Donnell).

may be a loss of confinement under off-normal and credible accident conditions, but also a site-specific analysis to assess the effects of a non-credible, beyond-design-basis accident at the PFSF site. It offers no legal or technical basis for supporting its assertion that PFS must undertake such an analysis in order to justify its exemption request. Nor is there any regulatory requirement to analyze the dose consequences of a beyond-design basis accident. Waters Dir. at A16.

R457. In fact, PFS performed two radiological dose analyses specific to the PFS exemption request. PFS performed a non-mechanistic cask tipover analysis for the PFSF and determined that a cask tipover – which is a beyond design basis event – would have no adverse radiological dose consequences. Singh/Soler/Redmond Dir. at A19, A38. Additionally, PFS further evaluated the results of its analyses to determine what effect a multiple cask tipover would have on radiological dose rates at the PFSF. Singh/Soler/Redmond Dir. at A23-A28.

R458. In addition, the Staff performed independent, site-specific analyses of the radiological doses that would result from a non-mechanistic cask tipover event and confirmed that the regulatory dose limits would not be exceeded under any postulated scenario.[229] Thus, there is no factual basis for the State's assertion that no radiological dose analyses have been performed specific to the exemption request.

R459. The State contends that "in this part of the proceeding PFS is relying on 'conservatism's' built into the PFS' design." State F. ¶ 549. This, however, mischaracterizes the PFS testimony on radiological dose consequences. Those conservatisms do exist, are extensively discussed in Section ~~IV.F~~ IV.G above (as they pertain to PFS's seismic exemption), and are applicable to the radiological dose conse-

[229] In addition, both PFS and the Staff performed analyses that demonstrated that the casks will not tip over even in a 10,000-year beyond-design basis accident.

quences analysis in that they provide assurance that the casks will not tip over even in a beyond-design basis seismic event. PFS, however, does not rely on those conservatisms to demonstrate compliance with radiological dose limit requirements. On the other hand, there are two additional types of conservatisms that are specific to radiological dose consequences: (1) conservatisms in the construction of the HI-STORM 100 System, and (2) conservatisms in assumptions regarding the radiological doses emanating from the loaded storage casks.

R460. Significant conservatisms exist in the design of each of the components of the HI-STORM 100 System including the MPC, and of the storage casks itself. PFS has offered extensive, uncontroverted testimony regarding the beyond design limit margins contained in each of the components of the cask. See, e.g., Singer/Soler/Redmond Dir. at A38. Additionally, PFS has made many conservative assumptions in its radiological dose calculations, including very conservative assumptions regarding the condition of the fuel present at the PFSF site that are either highly improbable or physically impossible. Singer/Soler/Redmond Dir. at A28. The various conservatisms in the PFS analyses are independent of each other and of other design conservatisms.

R461. The State attempts to challenge Dr. Redmond's evaluation of a beyond design basis accident at the PFSF by asserting that his "starting premise" was "that the casks would not tip over and that any damage to the casks if they tipped over would be 'localized', although he could not quantify the effect." State F. ¶ 549, citing Tr. 12068-69, 12093, 12097-98 (Redmond). A review of those transcript pages shows that Dr. Redmond did quantify the extent of the anticipated damage. Dr. Redmond specifically testified that the damage would be no larger than the size of the vents that are small compared to the size of the cask.[230] The State, on the other hand, has offered no evidence that any damage that may occur upon cask tipover would be anything other than localized deformations. By contrast, as discussed below, PFS has presented extensive evidence – both in oral testimony and in supporting analyses – that the casks would experience, at worst, localized damage in a tip over scenario.[231]

R462. The State contends that "Dr. Resnikoff calculated that the total dose from an array of tipped over casks, from direct gamma radiation, direct neutron radiation, and photons, would be 150 millirem per year." State F. ¶ 550. This is an incorrect reading of the record. Dr. Resnikoff, after making six corrections to his testimony, reached a 150 millirem per year dose, then made additional corrections to correct other errors, including using the wrong distance from the nearest cask to

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[230] The actual exchange at the hearing was as follows:

> MS. CHANCELLOR: In answer 36, you state that, "Any damage to the cask from a tip-over would be localized." And what is the basis of your opinion that the damage to the cask would be localized? And can you quantify what you mean by "localized"? Would it be as large as the vents? Would it be as big as a quarter? Would it be . . . what do you mean by "localized"?
>
> DR. REDMOND: Localized is kind of a generic term. The vents are fairly large, but relative to the overall surface area of the overpack, it's quite small, so . . .
>
> MS. CHANCELLOR: That's what, ten inches by fifteen inches?
>
> DR. REDMOND: Some of them. The ones on the bottom are. The ones on the top are six by twenty-five, six inches by twenty-five. So in that sense, it's localized relative to the large surface area of the overpack. So localized is . . . has, you know . . . can vary a little bit. Certainly, something the size of a quarter is localized. Now as far as the damage goes, it's my opinion that the damage from a cask tipping over would be localized.

Tr. 12096-97 (Redmond).

[231] The State also asserts that Dr. Redmond has no experience in how the casks would be oriented if they fell over. State F. 549. As discussed below, Dr. Redmond performed a further analysis of the cask in a tipped over position and concluded that there would be no change in radiological dose consequences even if the bottom of ~~a row of~~ a cask~~s~~ faced an OCA boundary. Tr. ~~12062~~ 12061-63 (Redmond).

the OCA boundary, and using the wrong value for neutron dose radiation at one meter from the cask. Correction of these additional errors further reduced Dr. Resnikoff's dose calculation below the 150 millirem value. See PFS F. 540-47.

R463. The State likewise claims that Dr. Resnikoff's calculations are conservative in that they did not take into account the additional effects of cask heat up or include the effect of other dose contributors. State F. ¶ 550. Dr. Resnikoff, however, included in his calculation the doses due to Cobalt-60 and Cesium-137 because, as the State admits, they are the main contributors to gamma doses. Id. Therefore, to the extent that the effect of other dose contributors was not addressed in Dr. Resnikoff's analyses, their absence does not introduce any significant conservatism to Dr. Resnikoff's analyses.

R464. There is some confusion in the record as to whether Dr. Resnikoff's calculations included the additional effects of cask heatup.[232] Whether or not such was the case, the potential cask heat up and attendant of loss of hydrogen postulated by Dr. Resnikoff would not affect the dose rate emanating from the cask in Dr. Resnikoff's analysis, because Dr. Resnikoff presumed that the only shielding available was the 2" steel baseplate that shields the annular region and no concrete. See State Exh. 141 at 2 ("The annulus creates a ring in which it is possible for streams of radiation to pass through without being shielded by any concrete . . . ." (emphasis added)); see also Tr. 12489-90 (Resnikoff). Thus, assuming a total loss

[232] The State asserts in State F. 550 that Dr. Resnikoff's total dose calculation does not include the effects of cask heatup (i.e., the neutrons that failed to be absorbed because of loss of hydrogen from the concrete due to water boiloff). However, at various points during the hearing Dr. Resnikoff testified that his dose computation included neutron and neutron-emitted photons. Tr. 12356, 12360-61. He also testified that he had "looked into heatup and increased neutron dose due to hydrogen loss." Tr. 12406-07 (Resnikoff). On the other hand, as the State points out, he also at one point stated that he had not taken into account the effect of cask heatup on radiation exposure. Tr. 12373-74 (Resnikoff).

of hydrogen shielding from all concrete does not affect Dr. Resnikoff's dose calculation in State Exh. 141A. Likewise, the State has postulated no scenario under which a row of casks could tip over and subsequently lose significant hydrogen shielding.

R465. The State also claims that PFS should perform a Monte Carlo dose calculation "especially with respect to the bottom of tipped over casks," even though the State acknowledges that Dr. Resnikoff did not perform such a calculation. State F. ¶ 551. As will be seen below, such an analysis is neither required nor warranted.

R466. The State asserts that Dr. Resnikoff identified areas where PFS had "applied an incorrect standard or performed an inadequate technical analysis of the potential for exceeding the dose limits in 10 CFR § 72.106,"[233] including not using an around-the-clock occupancy factor, i.e. 8,760 hours/year, not specifying an accident duration, and not performing a calculation regarding the dose consequences of a cask tipover event. State F. ¶ 552. In fact, each of these assertions is predicated on an inaccurate premise. The first two assertions are based upon an incorrect reading of 10 C.F.R. § 72.106(b). As discussed immediately below in ~~Section ____, supra,~~ 10 C.F.R. § 72.106(b) neither requires that the accident dose be calculated on an 8,760 hour year; nor specifies a particular accident duration. Likewise, as discussed further below, PFS did perform a dose consequence analysis of credible beyond design basis accidents.

(2) Applicable Radiological Dose Standard

[233] The State cites Dr. Resnikoff's pre-filed testimony for this proposition. In fact, 10 C.F.R. § 72.106 appears nowhere in the text of Dr. Resnikoff's testimony nor in the exhibits accompanying that testimony. Indeed, at the direction of State Counsel, Dr. Resnikoff framed his testimony around the normal operation dose limits of 10 C.F.R. § 72.104 (a), even though he testified that 10 C.F.R. § 72.106(b) is the applicable standard. Tr. 12376 (Resnikoff).

R467. With respect to the applicable regulatory standard, the State convolutedly argues that:

> (1) If no exemption had been applied for and the current deterministic earthquake definition standard applied, the radiological dose consequence standard applicable to the PFSF would be 10 C.F.R. § 72.106(b).
>
> (2) If the record shows that PFS has provided supportable analysis for a 10,000-year mean return period event, the standard in 10 C.F.R. § 72.106(b) would also apply.
>
> (3) However, if PFS applied (as it has done) for an exemption allowing its use of a probabilistic, 2,000 year return period earthquake analysis, then it must be held to a different standard, that in 10 C.F.R. § 72.104(a).
>
> State F. ¶ 554.

R468. This strained argument is advanced by the State for the first time in its proposed post-hearing findings, and is therefore untimely raised and impermissible for the reasons discussed in Section II. In addition, it would be anomalous to establish a standard under which the maximum radiological doses to which the public may be exposed depended on the magnitude of the design basis earthquake. Thus, the Board should reject this argument, which is nothing but an effort by the State to revive the applicability of 10 C.F.R. § 72.104(a) after it was disowned by its own witness at the hearing. See Tr. 12736 (Resnikoff). Of course, the extreme lateness of the argument is also an independent ground for its rejection.

R469. The State asserts that the applicable standard to be applied to an accident at the PFS is 10 C.F.R. § 72.104(a), because the rulemaking plan of SECY 98-126 recommended that an applicant demonstrate compliance with that regulatory provision. State F. ¶ 553. The State grudgingly recognizes that SECY 98-126 was superseded to remove the reference to 10 CFR §72.104(a), making Section

72.106(b) "arguably" applicable to the PFSF. Id. Even in the framing of this argument, the State is trying to create a new legal rule under which all exemption requests would have to comply with any existing rulemaking plan, thus giving a rulemaking plan the force of law. The State persists in making this argument, even though both the Commission and the Board ruled, in admitting Section E of Contention L/QQ into this proceeding, that PFS was not bound by the rulemaking plan in SECY 98-126. This legally untenable argument is the basis for the State's contention that 10 C.F.R. § 72.104(a) is the appropriate radiological dose standard. State F. ¶ 554.

R470. The State builds on this first erroneous argument to make a second, equally flawed one: that application of 10 C.F.R. § 72.106(b) would constitute "expanding the effect of PFS's request to be exempted from 10 C.F.R. § 72.102," by diluting the standard in 10 C.F.R. § 72.106(b). State F. ¶ 554. This argument makes no sense for at least two reasons. First, the radiation dose consequence limit under 10 C.F.R. § 72.106(b) is five (5) rem, regardless of the design basis of the facility or the magnitude of the design basis earthquake. Whether PFS designed its facility to a 1,000-year, 2,000-year, or 10,000-year DBE, the same 5 rem limit would apply to all designs.

R471. Second, the State implicitly and incorrectly presumes that an exemption from one regulatory provision would not be applied to other regulations that are invoked by the changed one. In fact, a change in the design basis ~~establishes the design basis~~ just means that all applicable regulations are to be applied to the new design; there is no need or requirement to ask when seeking an exemption that all applicable regulations be "transferred over" to the new design, as the State appears to argue (of course, without authority). In this case, the regulations provide a 5 rem dose limit for an accident at an ISFSI, whatever its design basis.

2. Calculation of Accident Dose Under 10 C.F.R. § 72.106(b)

a) Occupancy Time

R472. The State attacks the use of a 2,000-hour year for PFS's evaluation of a non-credible, beyond design basis cask tipover event because (1) the uncontrolled area beyond the OCA could be occupied in the future (State F. ¶¶ 555, 557),[234] (2) both the Staff witness, Mr. Waters, and the State's witness, Dr. Resnikoff, calculated an accident dose assuming an individual present at the boundary for twenty-four hours a day (State F. ¶¶ 556, 558); and (3) the State interprets § 72.106(b) to require an 8,760 hour occupancy time because it does not include language referring to doses to a "real" individual. State F. ¶559. None of these arguments has merit.

(1) Land Use Surrounding the PFSF Site

R473. The State would have the Board find that it is difficult to predict what conditions will be surrounding the PFSF site in 20 or 40 years. State F. ¶ 557. The parties agree that the nearest dwelling to the PFSF site is over two miles away. There is no evidence even suggesting that the land use surrounding the PFSF site will or is likely to change in any regard. In fact, land on two sides of the PFSF forms a buffer zone where land use cannot change (Tr. 12562 (Donnell)), and there are

[234] The State cites Mr. Donnell as stating that PFS "has no way of excluding anyone from the northern part of the controlled area because it does not own the property. Tr. (Donnell) at 12579-82." State F. 557. Mr. Donnell said nothing of that sort. Mr. Donnell testified that there were some parcels of land north of the site that were privately owned. The State never cross-examined Mr. Donnell on whether PFS could exclude those private landowners from the vicinity of the site in the event of an accident assuming they did not voluntarily chose to stay away.

considerable impediments to any change of land use for Bureau of Land Management land surrounding the PFSF site (Tr. 12564-65 (Donnell)). Additionally, the evidence also shows that the existing land use of the private land to the north of the PFSF site – livestock grazing – is unlikely to change in the foreseeable future. Tr. 12563-65 (Donnell). Thus, there is no evidence of record to suggest that a different land use should be presumed in applying a real individual standard under 10 CFR § 72.106(b), or to indicate that it is reasonable to assume that people will be stationed at the OCA boundary continuously from the onset of the accident onwards.

(2) Use of a 24-hour Per Day Occupancy Rate by State and Staff Witnesses

R474. The use of an 8,760 hour/year occupancy assumption by Dr. Resnikoff in his accident dose calculation and the use of a 720 hour accident duration in Mr. Waters' accident dose calculation are not relevant to whether 10 CFR § 72.106(b) requires that the calculation assumes a 24-hour per day occupancy rate. First, Dr. Resnikoff made his dose calculation pursuant to 10 CFR § 72.104(a) (Resnikoff Dir. at A11-A13; St. Exh. 141; St. Exh. 141A; Tr. 12376 (Resnikoff)), not § 72.106(b), and offered no testimony regarding his opinion of how radiological doses should be calculated under § 72.106(b). Second, Dr. Resnikoff's use of an 8,760 hour/ year occupancy for his § 72.104(a) dose calculations is clearly at variance with the actual text of § 72.104(a) which even the State now admits requires that it be calculated for a real, rather than an hypothetical individual. See State F. ¶ 559. Even Dr. Resnikoff has conceded that it is incorrect to use an 8,760 hour/year occupancy assumption in calculating doses under § 72.104(a).

Tr. 12436-37 (Resnikoff); see also Singh/Soler/Redmond Dir. at A29; Tr. 12263-65 (Waters)

R475. When Mr. Waters calculated accident dose consequences, he used a 720-hour assumed accident duration, *but not* an 8,760-hour year standard, because he calculated the maximum radiological dose consequences during a thirty day period after a hypothetical cask tipover event (Waters Dir. at A21), or from a hypothetical the loss of hydrogen in the cask due to cask heat up (Waters Dir. at A.20). (The thirty day period translates into 720 hours, not 8,760 hours.) In each case, Mr. Waters was following the guidance provided by NUREG 1567 regarding calculating design basis accidents that involve loss of confinement of a storage cask. Tr. 12221-22 (Waters); see also Staff Exh. 53 at 9-15. The procedures prescribed by NUREG 1567 address how to calculate the dose consequences of a loss of confinement accident, assuming a 720 hour release duration. This regulatory guidance is used by the Staff in calculating direct radiation dose as well. Tr. 12222 (Waters). These procedures apply to off-normal conditions, which are defined as events that are expected to occur with moderate frequency or once per calendar year. NUREG 1567, §15.1; Tr. 12222-23 (Waters). As discussed above, a seismically induced cask tipover event at the PFSF site would not fall under the category of an off-normal event. Tr. 12222-34 (Waters).

(3) Applicability of Real Individual Standard

R476. The State argues that the use of the term "any individual" in 10 C.F.R. § 72.106(b), as opposed to the use of the term "any real individual" in 10 C.F.R. § 72.104(a) is dispositive in distinguishing §72.106(b) from §72.104(a)'s real person standard, State F. ¶ 559, despite previously having argued that §72.104(a) requires a hypothetical person be used to calculate dose rates.[235] However, the State's attempt to differentiate the language of Sections 72.104(a) and 72.106(b) is without legal merit.

R477. The State's interpretation is belied both by the language of 10 CFR § 72.106, the Federal Register notice promulgating § 72.106, and by case law interpreting similar language in 10 CFR § 20.1201. Section 72.104(a) provides criteria for direct radiation from an ISFSI during normal operations, setting "the annual dose equivalent to any real individual who is located beyond the controlled area." Section 72.106 specifically addresses radiation dose levels from design basis accidents at an ISFSI and requires that the controlled area of an ISFSI be established so that:

> [a]ny individual located on or beyond the nearest boundary of the controlled area may not receive from any design basis accident the more limiting of a total effective dose equivalent of 0.05 Sv (5 rem), or the sum of the deep-dose equivalent and the committed dose equivalent to any individual organ or tissue (other than the lens of the eye) of 0.5 Sv (50 rem).

10 CFR § 72.106(b). While the State asserts that the omission of the adjective "real" from Section 72.106(b) indicates that Sections 72.104(a) and 72.106(b) should be interpreted differently (State F. ¶ 559), there is no support in the regulation or the Federal Register notice promulgating the regulation to support this assertion.

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[235] As discussed above, the State and its witness, Dr. Resnikoff, previously refused to concede that § 72.104(a)'s real person standard may result in a lower occupancy time than 8,760 hours. <u>See</u> Resnikoff Dir. at A10-A11. Dr. Resnikoff stated that "I calculated the correct annual dose rate assuming a <u>hypothetical</u> individual remained at the site boundary for 8,760 hours." Resnikoff Dir. at A11 (emphasis added); <u>see also</u> Resnikoff Dir. at A10 ("To assure that the public is protected, PFS must calculate a radiation dose assuming a hypothetical individual is located at the site boundary the entire year or 8,760 hours/year . . . .").

R478. The current version of 10 CFR § 72.106(b) was amended in 1998 to conform the calculation of the accident basis dose to the calculational methodology used in 10 CFR Part 20.[236] See Minor Revision of Design Basis Accident Dose Limits for Independent Spent Fuel Storage and Monitored Retrievable Storage Installations, Final Rule, 63 Fed. Reg. 54,559, 54,560 (1998). In amending § 72.106(b), the Commission expressed its intent as follows: "This final rule makes § 72.106 consistent with part 20 dose calculational methodology." 63 Fed. Reg. 54,560.

R479. Under part 20, in calculating the total effective dose equivalent to the individual likely to receive, the dose should be calculated or measured in regard to a real individual rather than a hypothetical individual. 10 CFR § 20.1302; Hydro Resources, ASLBP No. 95-706-01-ML; LBP-99-15, 1999 NRC LEXIS 60 (1999). By analogy, this would apply equally to § 72.106(b) since both regulations refer to "any individual".

(4) Accident Duration

R480. The State's position on accident duration is summarized in State F. ¶ 573. As indicated there, the State asks the Board to find that an accident at the PFSF "cannot be considered to have ended until the casks have been restored to a condition in which their radioactive emissions are within the limits for normal operation, i.e., the limits in 10 C.F.R. § 72.104(a)." State F. ¶ 573. The State further requests

[236] PFS filed its application in 1997, when the prior version of § 72.106 was still in effect. The prior version of the regulation provided:

> Any individual located on or beyond the nearest boundary of the controlled area shall not receive a dose greater than 5 rem to the whole body or any organ from any design basis accident. The minimum distance from the spent fuel or high-level radioactive waste handling and storage nearest boundary of the controlled area shall be at least 100 meters. 53 Fed. Reg. 31,658 (Aug. 19, 1988).

the Board to hold that PFS must (a) provide a contingency plan for how it will upright the casks, or (b) conduct an analysis to determine whether "post-accident, the casks would comply with the dose limits in 10 C.F.R. § 72.104(a)" under "normal operating conditions." Id.

R481. Pursuant to this theory, the State asserts that PFS is required to determine an accident duration for a cask tipover event and to develop contingency plans for uprighting casks in case of such an event and has failed to do so. State F. ¶ 560. This assertion is made without either legal or factual support. In fact, the record shows that this theory was raised for the first time by State counsel during the hearing.[237] The uncontroverted evidence shows that under a worst-case accident scenario postulated for the PFSF, the dose limits of 10 C.F.R. §72.106(b) would never be exceeded. Tr. 12620 (Resnikoff). See PFS F. 548. Moreover, the State is requesting a wholesale expansion of Commission regulations to include beyond design basis accident contingency planning. Current Commission regulations require contingency planning for only design basis accident.[238] A cask tipover at

[237] Neither the Unified Contention nor Dr. Resnikoff's pre-filed testimony has any reference to contingency or other types of emergency planning. On cross-examination of Staff witness Mr. Waters, on June 25, 2002, counsel for the State raised the issue of contingency planning for the first time in this proceeding. Tr. 12269 (Chancellor). Dr. Resnikoff first opined about the absence of such planning later the same day (Tr. 12509 (Resnikoff)), and first proposed that such contingency plans were necessary for beyond design basis accidents at an ISFSI the following day in his oral rebuttal testimony. Tr. 12533 (Resnikoff). It goes without saying that a contention that is raised so late must be disregarded. See Section II above.

[238] The State's witness, Dr. Resnikoff, was asked generally by State counsel if he was aware whether the "NRC does contingency planning or requires contingency planning for beyond design basis accidents," (Tr. 12533 (Curran)) to which he replied:

> Oh, absolutely. There's planning, for instance, for reactor meltdowns. There's contingency planning for that. I think that should hold here as well. There should be contingency planning for over design basis accident, whatever that over design basis is, 2,000 or 10,000.

Tr. 12533 (Resnikoff). Despite Dr. Resnikoff's enthusiasm for contingency planning for beyond design basis accidents at an ISFSI, he made reference to no rules, regulations, or guidance documents requiring such planning, and indeed admitted that he is not aware of the apthe PFSF is a hypothetical, beyond-design-basis event. Therefore, no contingency planning is required for such an event. Tr. 12269 (Waters). The State is requesting the Board to impose additional regulatory requirements on the PFSF, contrary to its authority.

b) Use of Thirty Day Accident Duration

R482. The State attacks the use of an assumed thirty-day accident duration by the NRC Staff witness, Mr. Waters because there is no evidence that his opinion is based on the existence of any contingency plan or actual knowledge of the accident's duration. State F. ¶ 561. There is no regulatory requirement to specify the duration of a beyond design basis accident at an ISFSI.[239] Moreover, as a matter of

plicable regulations for ISFSIs. Tr. 12629 (Resnikoff). Dr. Resnikoff's testimony rather than offering any evidence, proposes a rule change for regulations applying to an ISFSI, which is beyond the scope of this proceeding.

[239] The State also cites Dr. Redmond, claiming that PFS thought "it would be reasonable to assume an accident lasts for 30 days" (State F. 560). This gives the incorrect impression that the testimony referred to an accident at the PFSF site. In fact, it referred to a calculation for the HI-TRAC. The full colloquy went as follows:

> MS. CHANCELLOR: In Section [106(b)] for the accident dose analysis, it states, "Any individual located on or beyond the nearest boundary of the Controlled Area, may not receive from any design-basis accident the more limited of a total effective dose equivalent of 5 rem." What is the -- for purposes of your testimony that has been pre-filed, what is the duration time applicable to the 5 rem accident limit in 106b?
>
> DR. REDMOND: The analysis that's been done for Private Fuel Storage did not analyze tip-over of the casks, because it was hypothetical, so we did not do that. And in that regard, there is no dose consequences to the HI-STORM overpack. There was reference back to the HI-STORM FSAR for accident conditions related to the Hi-TRAC transfer cask. And the analysis in the HI-STORM FSAR assumed a 30 day duration for the accident.
>
> MS. CHANCELLOR: Thirty day duration. Sorry, I didn't hear the last part.
>
> DR. REDMOND: Thirty day duration for the accident associated with the *Hi-TRAC* transfer cask.
>
> MS. CHANCELLOR: And what was the doses of the 30 day duration for the *HI-TRAC?*
>
> DR. REDMOND: With regulatory guidance by the NRC, I believe in NUREG 1536.

Tr. 12092-93 (Chancellor/Redmond) (emphases added).

fact the State misunderstands the use of the thirty-day accident period by Mr. Waters and NUREG-1567, Standard Review Plan for Spent Fuel Dry Storage Facilities. The State asserts that the duration of an accident depends on "how long it would take to restore the site to pre-accident conditions." State F. ¶ 561. In fact, there is neither a safety need nor a regulatory requirement to restore the site to pre-accident conditions as a means of bringing the site within compliance for radiological dose consequences under 10 C.F.R. § 72.106(b). As Mr. Waters testified, the important factors in event of an accident are time, distance, and shielding, all of which reduce radiological dose levels. Each of these methods of assuring compliance with radiological dose requirements under the NRC regulations can be easily put into effect at the PFSF site within the thirty-day period used by Mr. Waters as the accident duration.

c) Cask Heat Up

R483. The State contends that if an accident lasts more than thirty days, there is the *potential* for an increase in neutron radiation. State F. ¶ 562. There is, however, no credible testimony supporting such a theory.[240]

R484. The State references the fact that the CoC for Holtec's HI-STORM 100 System requires that the ducts on a cask be cleaned every 33 hours. State F. ¶ 562. From

[240] The State cites Dr. Resnikoff for the proposition that heat up of the concrete has an adverse effect on neutron dose shielding, but Dr. Resnikoff's testimony carries no weight. Dr. Resnikoff made no attempt to calculate the degree to which a tipped cask may heat up (Tr. 12424, 12426 (Resnikoff)), or the amount of hydrogen loss that would take place if a HI-STORM 100 cask tipped over. He also had no idea of how to calculate the thermal degradation of the cask's concrete over time (PFS Exh. 240 at 90-93); nor had he ever used computer programs that computed the temperature of concrete over time (Id.). He also did not know how to estimate the reduction in shielding due to concrete heating up over time (Id. at 93). Indeed, this was his first attempt to examine thermal degradation in concrete and quantify the loss of radiation shielding that may result. Tr. 12418-19 (Resnikoff). Dr. Resnikoff was also not aware of the actual physics of hydrogen evaporation from concrete when he made his calculations. Tr. 12422 (Resnikoff).

that, the State infers that if the internal cask temperature increases (which may occur if the air inlet ducts are completely blocked for an extended period of time), this could lead to a loss of hydrogen by the cask concrete. Id. However, the State misunderstands the significance of the thirty-three hour time period contained in the Holtec CoC. Tr. 12152-55 (Singh); see PFS F. 520-523 for details. The short answer to the State's convoluted and ultimately irrelevant argument is that (1) the CoC calculation is totally unrelated to potential increases in neutron emissions even if the casks are not righted up within 30 days; (2) it is physically impossible for all ducts to become blocked after a cask tipover, and (3) water will not evaporate from the concrete in the manner or to the extent posited by the State, because the temperature within the cask will never reach the level at which that becomes possible. Id. Thus potential cask heatup is not a potential mechanism for the increase in neutron emissions.

d) Remedial Measures

(1) Time

R485. The State hypothesizes that it will take a considerable length of time to upright all the casks at the PFSF. State F. ¶ 563. While PFS witnesses testified at the hearing about the procedures that would be used to right up tipped over casks, the State would reject that testimony because there are no contingency plans in place that demonstrate that PFS will undertake any of these procedures. State F. ¶¶ 564-565. As discussed earlier, there is no regulatory requirement for such contingency planning, and the State's attempt to impose this additional regulatory burden is contrary to Commission regulations and case law.

R486. Time is also a significant factor in the mitigation of the radiological dose consequences of a hypothetical cask tipover event because the radionuclides that are the main contributors to the doses at the OCA boundary decay with time and, because of that decay, doses at the boundary would never reach the limit set in 10 C.F.R. § 72.106(b) even if no remedial measures were taken. Tr. 12619-20 (Resnikoff).

(2) Distance

R487. The land use around the PFSF would prevent exposure of the public to the radiological doses consequences of a hypothetical beyond design basis accident and there are no known plans for land use changes. Tr. 12559-65 (Donnell).

R488. Of course, the main distance factor would be the evacuation of residents in the vicinity of the site, a measure that can logically be expected to be taken and which would be 100% effective in limiting doses at the OCA boundary. The State fails to address Mr. Waters' testimony (Tr. 12267 (Waters)) that he would expect that people near the fence post would have been moved away within 30 days of an accident. State F. ¶ 561. Such evacuations are routinely implemented, sometimes with only a few hours notice, in the event of natural disasters such as hurricanes, tornadoes and floods. There is no reason why such an evacuation could not be ordered at the PFSF if it ever became necessary.

(3) Shielding

R489. Dr. Redmond, Mr. Donnell, and even Dr. Resnikoff testified that there are numerous measures that could be taken to shield the OCA boundary from radiological releases. The State mentions these measures but dismisses them because (1) they would not terminate the accident as the State defines it (i.e., restore the casks to an upright position and keep radiological releases within the 10 C.F.R. § 72.104(a) limits) (State F. ¶ 565), and (2) they were not submitted as contingency plans with the exemption request (State F. ¶ 572). Through these legalistic (and erroneous) grounds, the State would have the Board disregard the uncontradicted evidence on the ease of shielding adjacent property in the event of a hypothetical cask tipover event or cask heat up, if such measures would be required. For example, the State's own witness, Dr. Resnikoff, agreed that the construction of an earthen berm would be an appropriate remedial action. Tr. 12622-23 (Resnikoff). It is also one that could easily be taken to assure that radiological dose levels at the boundary of the OCA do not exceed regulatory limits. See Tr. 12583-84 (Donnell). Likewise, testimony regarding the use of steel plates, equipment and other types of shielding was offered by Dr. Redmond. Tr. 12126-27 (Redmond). In short, there are numerous ways in which a tipped over cask or casks may be shielded to comply with accident dose limits at the OCA boundary if necessary. The State contends that shielding the casks will not end the accident. State F. ¶ 565. However, it is beyond dispute that the use of shielding can assure that accident dose limits are complied with if it is necessary to take remedial action.

e) Palisades

R490. The State further argues that an event can last for many years as evidenced by incident involving a multiple purpose dry storage cask canister at the Palisades nuclear reactor site. State F. ¶ 566. The State's own witness, Dr. Resnikoff, admitted that the Palisades event had no radiological dose consequences, thus eliminating it as an example that an "accident" condition could last for many years. Tr. 12634-36 (Resnikoff).[241] Nor does the Palisades event involve any issues that

[241] In fact, the use of the example by Dr. Resnikoff appeared to be to point out that he felt that the NRC engaged in "a strange way to regulate the industry, to allow [the owner of the Palisades plant] to have cracked casks sitting out on pads, and just having that happen." Tr. 12635 (Resnikoff). The use that Dr. Resnikoff wants to make of the Palisades situation as proof that the Staff cannot be relied upon to perform its duties appropriately is not an issue cognizable in an NRC licensing proceeding. See Section II above.

have been raised by the State in the present Contention L/QQ, nor does it involve any of the equipment proposed to be used at the PFSF.[242] It is, therefore, entirely irrelevant to the PFSF licensing proceeding.

R491. The State argues that remedial measures taken to assure compliance with 10 C.F.R. § 72.106(b) cannot be considered to be the end of an accident. State F. ¶ 569. Read literally, the State asserts that 10 C.F.R. § 72.106(b) must be complied with <u>in the absence of any remedial measures</u> (State F. ¶ 570), which is contrary to reality, a plain reading of the regulation, and Commission practice.

R492. In addition to arguing that an ISFSI cannot comply with Section 72.106(b) by taking remedial measures in the event of an accident, the State asserts, without any legal or legislative history support, that: (1) Section 72.106(b) does not contemplate the use of contingency measures to comply with its provisions (State F. ¶ 571); (2) allowing remedial measures to comply with NRC radiological dose regulations in the event of an accident violates the Commission's defense-in-depth strategy (State F. ¶ 572); and (3) if remedial measures can be taken to comply with radiological dose limits in the event of an accident, that such remedial measures should be specified as part of the license application (State F. ¶ 572). In each instance, the State not only fundamentally misunderstands the role of radiological dose limits, it is also requesting that the Board expand the Commission's regulations applicable to ISFSIs and create new regulatory requirements out of thin air.

R493. The State seems to misunderstand what 10 C.F.R. § 72.106(b) requires. Section 72.106(b) requires that "[a]ny individual located on or beyond the nearest bound-

[242] The Palisades event involved a different type of storage cask (a "VSC" cask). Tr. 12633 (Resnikoff).

ary of the controlled area may not receive from any design basis accident the more limiting of a total effective dose equivalent of 0.05 Sv (5 rem) . . . ." The regulation plainly does not dictate how maintaining doses below these limits is to be achieved.

f) Assumptions Regarding Configuration of Tipped-Over Casks

R494. The State asks the Board to make two findings regarding Holtec's non-mechanistic cask tipover analysis: (1) that more flattening may occur to a HI-STORM 100 cask than determined in that analysis due to an initial angular velocity larger than the zero value used by Holtec (State F. ¶ 574); and (2) that the PFS evaluation of radiological dose consequences of a non-mechanistic cask tipover was not sufficiently conservative because it did not presume that all casks will fall with their bottoms perpendicular to the OCA boundary (State F. ¶ 575-579). In both instances, the State's arguments are contrary to the record.

(1) Initial Angular Velocity

R495. The State asserts that the zero angular velocity used in the hypothetical cask tipover scenarios is improper, claiming that the testimony of Dr. Bartlett "refuted that assumption." State F. ¶ 574. In fact, Dr. Bartlett did nothing of the sort. Dr. Bartlett (whose expertise is on soils) summarily declared in reference to the Holtec non-mechanistic cask tipover analysis that "the tipover event postulated that the cask would be perched on its edge with zero angular velocity. During an earthquake, that's not true. If we go to tipover, we have some angular velocity." Tr. 12870-71 (Bartlett). This unsupported assumption, by one with no expertise on the subject, is hardly convincing evidence. Moreover, Dr. Bartlett admitted that he had not been involved in any calculations of cask stability or the results of a tipover event. Tr. 12870 (Bartlett). Therefore, his testimony can be characterized as little more than a guess. By contrast, extensive PFS testimony by experts qualified to evaluate a cask tipover analysis demonstrates that using an initial angular velocity of zero is an appropriate assumption because of physical considerations involving the mechanics of precessing bodies. Sing/Soler/Redmond Dir. at A39; see also, PFS F. 530-533.

R496. The State likewise asserts that "in his pre-filed testimony, Dr. Resnikoff raised the concern that if the initial angular velocity of the casks during tip over were greater than zero, then there would be more cask flattening than contemplated by PFS." State F. ¶ 574 (emphasis added). The State further asserts that it is also necessary to know "whether [the casks] have fallen onto each other, and whether [the casks] are stretched or flattened by the force of falling on each other . . . ." State F. ¶ 575. Yet, Dr. Resnikoff admitted at the hearing that he did not know whether a cask impact due to a beyond-design-basis seismic accident at the PFSF would cause flattening or other damage to the storage cask (Tr. 12406 (Resnikoff)), whether or how much cracking of the steel or concrete would occur (Tr. 12407-08 (Resnikoff)), or whether or how much thinning of the steel would occur (Tr. 12406 (Resnikoff)). Dr. Resnikoff further admitted that he did not know whether it is physically possible for one cask to fall on top of another prone cask (Tr. 12613 (Resnikoff)), had no detailed knowledge of the behavior of the casks during a seismic event (Tr. 12613 (Resnikoff)), and had no knowledge of how the casks might interact from a structural engineering standpoint (Tr. 12613 (Resnikoff)). Dr. Resnikoff also acknowledged that he had neither experience nor expertise in measuring or quantifying concrete cracking (PFS Exh. 240 at 42-45, 47, 71), determining the strength of steel or concrete (PFS Exh. 240 at 46), calculating the initial angular velocity of a cask during tipover (PFS Exh. 240 at 70-71; Tr. 12403-04 (Resnikoff)), or measuring or quantifying thinning or flattening of the steel in the cask shell due to impact (PFS Exh. 240 at 80-81). The record is thus devoid of any basis for Dr. Resnikoff's testimony on the nature or extent of any storage cask flattening (or any other cask damage mechanism), or his evaluation of Holtec's hypothetical cask tipover analysis. Therefore, there is no credible support for the allegation that tipover will cause cask flattening beyond that assumed by PFS.

(2) Orientation of Casks During a Tipover Event

R497. The State argues that it is necessary to take into account the orientation of the casks to determine the radiological dose consequences at the OCA boundary in the event of a hypothetical cask tipover. State F. ¶ 575. The State claims that Dr. Resnikoff's "analysis" of a cask tipover event in which all bottoms of a row of 80 casks faced the OCA boundary was appropriate because it would be a conservative configuration that would maximize radiological dose levels at the OCA boundary. State F. ¶ 576. To support this alignment assumption, the State refers to the analysis conducted by Staff witness Mr. Waters (but not to the results thereof), who calculated dose consequences based on a scenario of 50 tipped over casks. State F. ¶ 577.[243]

R498. Both the predicate for the State's claim and its substance are groundless. All witnesses agree that if a beyond design basis accident were to cause HI-STORM 100 storage casks at the PFSF to tip over, that the orientation of such casks would be

[243] Mr. Waters concluded that even in that extreme case the radiological doses at the OCA boundary were within regulatory limits, see. Waters Dir. at A18-19. He prefaced the discussion of his analysis by noting that "beyond-design basis seismic events are not required to be considered in the licensing or evaluation of a proposed facility." Id. at A16.

random. Tr. 12428 (Resnikoff); Singh/Soler/Redmond Dir. at A23-A26; PFS F. 509-510. Indeed, Dr. Resnikoff testified that he did not know of any mechanism by which a row of casks could fall so that their bottoms would all face the OCA boundary. Tr. 12427-28 (Resnikoff). PFS analyzed a realistic scenario where the casks were presumed to be randomly oriented and determined that there would be no effective change in radiological dose levels from normal operating levels. Singh/Soler/Redmond Dir. at A20-A30

R499. Even assuming that all eighty casks in an outside row were to tip with their bottoms perpendicular to the OCA boundary as Dr. Resnikoff hypothesizes, the evidence demonstrates that the radiological dose limit of 10 C.F.R. § 72.106(b) would never be exceeded during such a tipover event. PFS F. 540-541. Mr. Waters agreed with the conclusions reached by Holtec's analysis of a multiple cask tipover noting that the dose rates from the sides of the casks would be diminished in a tipped over condition and that overall "one would not expect to see a significant increase . . . in off-site dose rates at any point of the OCA boundary. . . ." Waters Dir. at A21. In addressing a worst-case, cask tipover hypothetical, Mr. Waters concluded that the increase in dose rates under that scenario was well below the radiological dose limits of 10 C.F.R. § 72.106(b). Id.

g) Adequacy of Method Used by PFS to Calculate Doses

R500. The State argues that PFS could have conducted a Monte Carlo analysis of the radiological dose consequences of a cask tipover scenario, using Dr. Redmond's expertise in that methodology, "but chose not to apply the Monte Carlo method." State F. ¶ 581.[244] The State further contends that PFS's rationale for not conduct-

[244] What Dr. Redmond actually said in his testimony was that he performed a site-specific radiological dose analysis in support of the PFS license application in 1999, but did not perform a similar analysis in support of the exemption request. He was then asked whether, if he had

ing such an analysis – that a cask tipover event was a beyond design basis event – is insufficient to justify not conducting such an analysis. State F. ¶ 582. However, the State continues to provide no rationale for why an analysis of any kind, including a Monte Carlo analysis, is required for a hypothetical beyond design basis accident should be conducted, nor do they provide any suggestion as to which out of myriad theoretical beyond-design-basis accidents should be used to conduct such an analysis.

R501. The State would have the Board conclude that "the State has presented evidence of serious shortcomings in PFS's analytical method." State F. ¶ 584. In reality, the State has presented no evidence challenging the methodology of any of PFS's evaluation of the radiological dose consequences of a design basis accident, a hypothetical, non-mechanistic cask tipover, or multiple cask tipover in the event of a beyond design basis accident. It has presented no evidence that would predict that the casks will tip over under either a 2,000-year return period earthquake or a 10,000-year return period earthquake. Moreover, if a cask were to tipover, the only evidence in the record that analyzes the effect of such a tipover demonstrates that there will be no radiological dose consequences from such a tipover, either through damage to a cask (see, e.g.,Singh/Soler/Redmond Dir. at A19, A38) or through the tipover of multiple casks at the PFSF site (Singh/Soler/Redmond Dir. at A23-A28). Indeed, while the State questions whether the Holtec non-mechanistic analysis is correct in using an initial angular velocity of zero, the State has put no evidence in the record from a qualified witness that an initial an-

performed an analysis in support of the exemption request, he could have used Monte Carlo methods. He agreed that he could have. Tr. 12086-87 (Redmond). At no point did Dr. Redmond testify that he (or PFS) chose not to perform a Monte Carlo analysis for the exemption request.

gular velocity should be greater than zero. bThe State has also provided no evidence that any damage would occur to a storage cask if it were to tip over. The State has provided no authority for requiring performance of a Monte Carlo analysis for a beyond-design-basis accident. Moreover, even under a worst case, beyond-design-basis cask tipover accident with a total loss of hydrogen shielding and the bottoms of all casks pointed at the OCA boundary, the State has provided no evidence that the radiological dose limits of Section 72.106(b) will ever be exceeded.

R502. The State acknowledges that "it has not presented sufficient evidence to prove that doses will be above regulatory limits during an accident." State F. ¶ 584. It is, however, much worse than that. The State has presented no evidence that the doses established in 10 C.F.R. § 72.106(b) will be exceeded, and its own witness Dr. Resnikoff agrees that they never will be. Tr. 12619-20 (Resnikoff). What we have here is an abject failure by the State to meet its burden of coming forward. Additionally, there is overwhelming evidence of record demonstrating that no adverse radiological dose consequences would occur for any postulated beyond-design-basis event at the PFSF. Thus, its radioactive dose challenge to the granting of the exemption must be dismissed.

I. PUBLIC INTEREST

R503. The State incorrectly asserts that "[t]here was no evidence presented that the Staff considered the public interest in agreeing to PFS's exemption request." State F. ¶ 586. In fact, the Staff testified regarding at least three different ways ~~inw hich~~ in which the PFS exemption request was in the public interest: (1) the use of PSHA is in the public interest, (2) an interim spent fuel storage facility is in the public interest for a variety of reasons, and (3) having the facility constructed cost-effectively is in the public interest. See Section II.3, above.

R504. The State disingenuously refers only to Dr. McCann's discussion of the public benefit that accrues from having an ISFSI constructed cost effectively and asserts that the Board cannot consider costs in making its decision. State F. ¶ 587. As discussed in Section II.3, above, costs may be considered in the public interest. Moreover, the State ignores several factors proffered by the Staff for why the exemption request is in the public interest.

R505. First, Dr. Stamatakos testified that the use of probabilistic seismic hazard analysis in establishing the design basis of the PFSF was in the public interest because, *inter alia*, it was a better way to achieve the purposes of the regulations governing the siting of ISFSIs:

> . . . the exemption request takes advantage of significant advances in understanding of how best to quantify earthquake seismic hazard assessments, compare to an approach that, by all accounts, the deterministic approach has significant flaws. So in that aspect, we can argue that by moving toward a probabilistic society we're moving toward a better understanding and evaluation of hazards without incorporating unrealistic effects into our seismic hazard assessment. And again, our analysis is based on technical evaluation of the application and the exemption requests.

Tr. 8253 (Stamatakos); see also Tr. 8259-60 (McCann). Dr. Cornell similarly identified the advantages of the a probabilistic approach. Cornell Dir. at A16.[245] See Section II.3.c, above.

[245] As stated by Dr. Cornell there: (1) the probabilistic approach captures more fully the current scientific understanding of earthquake forecasting than the deterministic method; (2) the probabilistic approach is capable of reflecting the uncertainties in professional knowledge of key elements of the seismic hazard; and (3) the probabilistic approach can be used to set design criteria that are consistent among different regions and among different failure consequences, thus allowing a rational and a equitable allocation of safety resources.

R506. Second, the Staff found that the construction of an ISFSI was in the public interest. The NRC Staff in the Final Environmental Impact Statement explicitly addresses the public benefit that would accrue from the construction of the PFSF. Specifically, the FEIS states:

> The purpose of the proposed PFSF is to satisfy the need for an interim facility that would serve as a safe, efficient, and economical alternative to continued SNF storage at reactor sites. PFS has indicated that such an interim facility would ensure that (1) the operation of a nuclear power plant would not cease because of lack of SNF pool storage capacity; (2) permanently shut-down reactors could be decommissioned sooer, resulting in a savings to the reactor licensees and earlier use of the land for other activities; and (3) for some reactor licensees, an economical alternative to at-reactor ISFSIs would be available.

FEIS at xxxii-iii. This rationale was echoed by Dr. Chen's testimony. Tr. 8244-8245 (Chen).

R507. Finally, Dr. McCann raised the fact that a cost-effective ISFSI is also in the public interest. Tr. 8278 (McCann). Any of these public interests alone would be sufficient to find that the Staff considered the public interest. The discussion of all of these interests by the Staff in concert makes it clear that the public interest was considered. The State's only argument that relates to public interest is that this Board should give overriding consideration to the effects of the United States' atomic testing program on the citizens of Utah.[246] (State F. ¶ 588) is misplaced.

[246] The State also tries to raise safety as an issue describing the PFSF design as "not optimum" for Skull Valley, but health and safety is dealt with separate from the public interest. The State also tries,unpersuasively to distinguish between the public interest in an ISFSI for TMI fuel and an ISFSI for fuel from other reactors, without providing a well developed rationale for that distinction. State F. 588.

V. PROPOSED CONCLUSIONS OF LAW

The State sets forth a series of conclusions of laws that ~~re~~ are based on its proposed findings. Having rejected the State's proposed findings, we also reject its proposed conclusions of law and adopt the proposed conclusions of law set forth in PFS's Proposed Findings.

5/6/02

April 1, 2002

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of	)	
	)	
PRIVATE FUEL STORAGE, L.L.C.	)	Docket No. 72-22-ISFSI
	)	
(Independent Spent	)	
Fuel Storage Installation)	)	

N

NRC STAFF TESTIMONY OF VINCENT K. LUK
AND JACK GUTTMAN CONCERNING UNIFIED
CONTENTION UTAH L/QQ (GEOTECHNICAL ISSUES)

Q1. Please state your names, occupations, and by whom you are employed.

A1(a). My name is Jack Guttmann ("JG"). I am employed as Chief of the Technical Review Section, Spent Fuel Project Office ("SFPO"), Office of Nuclear Material Safety and Safeguards ("NMSS"), U.S. Nuclear Regulatory Commission ("NRC"), in Washington, D.C. A statement of my professional qualifications is attached hereto.

A1(b). My name is Vincent K. Luk ("VKL"). I am employed as a Principal Member of the Technical Staff in the Nuclear Technology Programs Department at Sandia National Laboratories ("SNL"), in Albuquerque, New Mexico. I am providing this testimony under a technical assistance contract between the staff of the U.S. Nuclear Regulatory Commission ("NRC Staff" or "Staff") and SNL. A statement of my professional qualifications is attached hereto.

Q2. Please describe your current responsibilities.

A2(a). (JG) As Chief of the Technical Review Section in the Spent Fuel Project Office, my responsibilities include direction and supervision of various technical reviews related to the licensing and certification of radioactive material transportation and storage packages, under 10 C.F.R. Parts 71 and 72, respectively, including technical reviews related to independent spent fuel storage installations ("ISFSIs"). Among my other responsibilities, I routinely direct and supervise the evaluation and use of computer code modeling and analytical methodologies in assessing the safety and performance of radioactive material transportation and storage packages.

A2(b). (VKL) I currently serve as Leader of the Structural Analysis and Evaluation Team for an NRC Integrated Vulnerability Assessment Project, examining the vulnerability and structural integrity of nuclear power plants subjected to external high-energy impacts. In addition, I serve as the Principal Investigator in an NRC project, establishing criteria and review guidelines in evaluating the seismic behavior of dry cask storage systems; and in examining the dynamic seismic behavior of free-standing dry cask storage systems and soil-structure interaction effects in simulated earthquake events.

Q3. Please explain what your duties have been in connection with the NRC Staff's review of the application filed by Private Fuel Storage, L.L.C. ("PFS" or "Applicant") for a license to construct and operate an Independent Spent Fuel Storage Installation ("ISFSI") on the Reservation of the Skull Valley Band of Goshute Indians, geographically located within Skull Valley, Utah (the "proposed PFS Facility").

A3(a). (JG) As Chief of the Technical Review Section in SFPO, I requested, through the Office of Nuclear Regulatory Research, that a confirmatory analysis be performed by Sandia National Laboratories on behalf of the Staff to evaluate the potential for cask sliding, collision and tipover at the proposed PFS Facility. This analysis was considered to be confirmatory in nature, ~~in that the Staff had previously concluded, on the basis of its review of~~ to verify the conclusions in the PFS application and supporting analyses, that tipover and collision of the casks on the PFS concrete storage pads will not occur under design basis seismic conditions. *See* Consolidated SER, §5.1.4.4, at 5-28 to 5-32; and NRC Staff Testimony of Goodluck I. Ofoegbu and Daniel J. Pomerening on Unified Contention Utah L/QQ, Part D. In addition, I and other members of my staff provided information and expertise, as appropriate, to assist in the review of cask stability under seismic conditions at the proposed PFS Facility.

A3(b). (VKL) As part of my official responsibilities, at the Staff's request I conducted an analysis to evaluate the seismic behavior and stability of the freestanding, cylindrical HI-STORM 100 casks to be installed on concrete pads at the proposed PFS facility, including the potential for cask sliding, collision and tipover. As Principal Investigator in this project, my role was to develop a three-dimensional coupled finite element model of the proposed PFS dry cask storage system to examine the nonlinear and dynamic behavior of the casks, and to simulate the effects of soil-structure interaction, under prescribed seismic conditions. I am the principal author of several documents describing this confirmatory analysis, including (1) "Summary Report on Seismic Analysis of HI-STORM 100 Casks at Private Fuel Storage (PFS) Facility," dated February 22, 2002; (2) "Seismic Analysis Report on HI-STORM 100 Casks at Private Fuel Storage (PFS) Facility," dated March 8, 2002; and (3) "Seismic Analysis Report on HI-STORM 100 Casks at Private Fuel Storage (PFS) Facility," Rev. 1, dated March 31, 2002 (herein cited as "Final Report, Rev. 1").

Q4. What is the purpose of this testimony?

A4. The purpose of this testimony is to provide the results of the NRC Staff's confirmatory analysis of the stability of the freestanding HI-STORM 100 casks at the proposed PFS Facility, with respect to the potential for cask sliding, collision and tipover under seismic conditions, as set forth in Unified Contention Utah L/QQ, Part D.1.i.

Q5. Are you familiar with Unified Contention Utah L/QQ, Part D.1.i. ?

A5. Yes. We understand that Part D.1.i. of this contention states:

> Because of the above errors, omissions and unsupported assumptions [stated in preceding portions of Contention Utah L/QQ, Part D], the Applicant has failed to demonstrate the stability of the free standing casks under design basis ground motions. Thus, the Applicant's analyses do not support the Applicant's conclusions that

excessive sliding and collision will not occur or that the casks will not tip over. 10 CFR § 72.122(b)(2) and NUREG-1536 at 3-6.

Q6. Please describe the Staff's analysis of the stability of the HI-STORM 100 casks and the potential for cask sliding, collision and tipover at the proposed PFS Facility?

A6. An ongoing generic program for developing guidance on seismic hazards analysis was established by NRC's Office of Nuclear Regulatory Research. A research team consisting of analysts and engineers from SNL, ANATECH Corporation, and Earth Mechanics, Inc., was assembled for this purpose, under the leadership of Dr. Vincent Luk, as Principal Investigator. As part of this ongoing effort, the Staff requested technical assistance from the Sandia National Laboratories in conducting an analysis of the behavior of loaded HI-STORM 100 storage casks under seismic conditions at the PFS Facility. The Staff provided basic information to the research team, with respect to cask design, pad dimensions, soil-cement layers under and adjacent to the pad, the site-specific soil profile, and time histories of seismic accelerations.

In conducting this analysis, three-dimensional coupled finite element models were developed, and seismic analyses were performed, to examine the dynamic and nonlinear behavior of the HI-STORM 100 casks to be installed on the concrete storage pads at the proposed PFS Facility, including the soil-structure interaction effects during a seismic event. Three different sets of seismic conditions were modeled: (1) the 2,000-year return period earthquake for the PFS Facility site; (2) the 10,000-year return period earthquake for the PFS Facility site; and (3) a sensitivity study based on the 1971 San Fernando Earthquake (Pacoima Dam record). The analyses thus modeled ground motions for the design basis 2,000-year event; the 1971 San Fernando Earthquake (Pacoima Dam record), for which the ground motions are somewhat similar to the ground motions of the PFS 2,000-year event; and ground motions for the PFS 10,000-year event, which significantly exceed the design basis ground motions for the proposed PFS Facility.

Q7. Please describe the nature of the model that was utilized in the analysis.

A7. (VKL) The ABAQUS/ Explicit code was used to analyze the three-dimensional coupled finite element models, that consist of a single cylindrical HI-STORM 100 cask (with the MPC-68 option), a flexible full-sized concrete pad (30-ft x 67-ft x 3-ft), a shallow surface layer of
a soil-cement layer adjacent to the pad (2'4" thick),
compact aggregate around the pad (5-ft x 10-ft x 8-in), a soil-cement layer under and adjacent to the pad (approximately 2-ft thick), and an underlying layered soil foundation. The layout of the entire coupled model is shown as Figure 1 of the Final Report, Rev. 1 (page 14). The cask was modeled as an elastic solid component, while the gravel, concrete pad, soil-cement, and soil were modeled as flexible linearly elastic materials. Structural damping ratios, whose values are tabulated in each horizontal layer and for each of the three cases of soil profile data (*see* Final Report, Rev. 1, Tables 2 to 7), were used for the soil and soil cement materials, while a zero damping was used for the concrete pad and the cask.

The shallow surface layer and the concrete pad are placed on a continuous 2-ft soil-cement layer that is on top of the soil foundation. The coupled model has three interfaces, which include the (1) cask/pad, (2) pad/soil-cement layer, and (3) soil-cement layer/soil foundation interfaces. In addition to incorporation of the aforementioned structural elements, development and use of the model also required selection of appropriate cask/pad and soil material properties and application of properly prescribed seismic time history sets to the model. To this end, the NRC staff provided the research team with the basic information on cask design, pad dimensions, soil-cement layers under and adjacent to the pad, the site-specific soil profile, and time histories of seismic accelerations. The analytical results obtained from the model address the dynamic and nonlinear response of the cylindrical cask in terms of its wobbling and sliding by examining closely the nonlinear contact behavior at the three interfaces and accounting for soil-structure interaction effects.

Q8. What assumptions did you make with respect to cask and pad, rigidity/elasticity and damping in your model?

A8. (VKL) The cask and pad were modeled as elastic bodies with zero damping.

Q9. Please describe the principal factors you considered in modeling and evaluating the dynamic response of the casks during an earthquake event?

A9. (VKL) This particular modeling effort focused on performing sensitivity studies on the cask response with respect to three key factors: (1) prescribed seismic loading, (2) coefficients of friction at the three interfaces in the coupled model, and (3) soil profile data used for the soil foundation model.

Q10. With respect to the first factor you identified (seismic loading), please describe the seismic loading conditions or events that were used in performing dynamic analyses of the cask.

A10. (VKL) Three sets of seismic time histories were used as input excitations in the coupled model analyses. First, a prescribed artificial time history of seismic accelerations with a duration of 30 seconds, using design basis response spectra for the PFS site for a 2,000-year return period earthquake, was used to generate the response of the cask under design basis conditions. Second, a similar site-specific time history of seismic accelerations for a 10,000-year return period with a duration of 30 seconds was used to provide a limiting or upper-bound case assessment of cask response. Third, a sensitivity study was performed using the 1971 San Fernando Earthquake, Pacoima Dam record.

Each set of seismic time histories has one vertical and two horizontal components of statistically independent seismic accelerations. For the 2,000-year return period earthquake, the peak ground accelerations ("PGAs") that were modeled, based on artificial time histories specific to the PFS site, were 0.728 g (horizontal, east-west), 0.707 g (horizontal, north-south), and 0.721 g (vertical); these PGAs envelop the 2,000-year design basis response spectra of 0.711 g (horizontal) and 0.695 g (vertical), stated in the Consolidated SER for the PFS Facility. For the 10,000-year return period event, the PGAs that were modeled, based on site-specific artificial time histories, were 1.25 g and 1.23 g for the horizontal components, and 1.33 g for the vertical component, which envelop the PFS earthquake hazard spectra. For the 1971 San Fernando Earthquake, Pacoima Dam record, the PGAs that were modeled were 0.641 g for the two horizontal components, and 0.433 g for the vertical component; the duration for this event was 41.8 seconds.

Each of the three seismic acceleration components of a set of time-histories was treated with a deconvolution procedure to produce a modified time history of deconvoluted accelerations with properly adjusted amplitudes and frequencies of the surface-defined accelerations. All three components of deconvoluted accelerations were applied simultaneously at the base of the soil foundation in the coupled model. Deconvolution is a mathematically rigorous solution process that applies the wave propagation equation of the free-field surface along with the boundary conditions, that modifies the seismic acceleration input to account for the site-specific soil properties (*i.e.*, linear shear modulus and viscous damping model). This serves to preserve the dynamic characteristics of the original seismic motions and achieve the desired (*i.e.*, appropriate) surface shaking intensity.

Q11. With respect to the second factor you mentioned (coefficients of friction at the three interfaces in the model), please describe how such coefficients were used in the coupled model.

A11. (VKL) Three interfaces were used in the coupled model: cask/pad, pad/soil-cement layer, and soil-cement layer/soil foundation. In order to determine the governing cases for both (a) the maximum horizontal sliding displacement, and (b) the angular rotation of the cask, different combinations with upper and lower bound coefficients of friction were used in the analyses. For the 2,000-year (design basis) event, the best estimate soil profile data (*see* discussion *infra*), a lower bound coefficient of friction of 0.20 (for investigating cask sliding) and an upper bound coefficient of friction of 0.80 (for investigating the potential for cask tipover) were used at the cask/pad interface; also, bounding coefficients of friction of either 1.00 or 0.31 were assumed at the other two interfaces, as shown in Table 8 of the Final Report, Rev. 1 (Best Estimate, Model Type 1) (at page 30).

These sensitivity studies showed that the maximum horizontal displacement (sliding) of the cask was obtained when using a coefficient of friction of 0.20 at the cask/pad interface and 0.31 at the pad/soil-cement layer and soil-cement layer/soil foundation interfaces, as shown in Table 8 of the Final Report, Rev. 1 (Best Estimate, Model Type 1). Consequently, this combination of coefficients of friction was selected as the governing case for other seismic analyses reported in Table 8 of the Final Report, Rev. 1 (page 30), for the 2,000-year event.

Similarly, several studies were conducted for the 1971 San Fernando Earthquake (Pacoima Dam record) and the 10,000-year return period event, using a coefficient of friction of 0.20 at the cask/pad interface, and 0.31 at the other two interfaces, in order to maximize the potential for horizontal displacement (sliding) of the cask. The results of these studies are shown in Tables 9 and 10 of the Final Report, Rev. 1 (pages 31-32). Finally, two additional analyses were conducted for the 1971 San Fernando Earthquake and the 10,000-year return period event, using a coefficient of friction of 0.80 at the cask/pad interface, and 1.00 at the other two interfaces, in order to maximize the potential for cask tipover. These results are also shown in Tables 9 and 10 of the Final Report, Rev. 1.

Q12. With respect to the third factor you identified (soil profile data), please describe the soil profile data used for the soil foundation model.

the 2'4" soil-cement layer, and the

A12. (VKL) As discussed above, the compact aggregate surface layer and concrete pad are placed on top of a 2-ft thick soil-cement layer that is on top of the soil foundation. The soil foundation submodel utilized in the model was 330-ft in the east-west direction and 757-ft in the north-south direction; these lateral dimensions exceed the recommended minimum as defined in

U.S. Corps. of Engineers soil-structure interaction modeling guidelines. Also, the coupled model partitions the soil into six horizontal layers to a depth of 140 feet, to represent the soil foundation; and the top surface was further divided into layers. The 140-ft depth was selected, in part, to reach a level below which the soil stiffness increases monotonically with depth. Sensitivity studies were performed to demonstrate the adequacy of this discretization scheme (using six layers to a depth of 140 feet) to incorporate the depth variation of soil properties such as shear wave velocity and damping profiles. As shown in Section 3.4.1 and Tables 2-7 of the Final Report, Rev. 1 (pages 9-12), specific soil properties considered include Young's Modulus, Poisson's ratio, density, damping ratio and a mass-related damping factor. This foundation modeling and its rationale are discussed in greater detail in sections 3.2.4 to 3.4.1 of the Final Report, Rev. 1 (pages 7-12).

To provide for broad variation in the soil properties, three sets of soil profile data - the best estimate, the lower bound, and the upper bound - were used separately in the analysis. The same soil profile data (best estimate, the lower bound, and upper bound) were used in performing the cask analyses for the seismic event with a 2,000-year return period and the 1971 San Fernando Earthquake, Pacoima Dam record, as shown in Tables 2 to 4 of the Final Report, Rev. 1 (pages 10-11). Different soil profile data were used for the 10,000-year return period seismic event, in which the shear modulus and damping of each layer of the soil foundation were adjusted for shear strains, as shown in Tables 5 to 7 of the Final Report, Rev. 1 (pages 11-12); in contrast, for seismic events with a 2,000-year return period, the low strain shear modulus and damping were used.

13. What does the coupled model predict as the maximum horizontal cask sliding displacements for each of the three seismic events considered?

A13. (VKL) The results from the seismic analyses indicate that the maximum horizontal cask sliding displacements are 3.98 inches for the 2,000-year return period event, 3.00 inches for the 1971 San Fernando Earthquake, Pacoima Dam record, and 15.94 inches for the 10,000-year return period event.

It should be noted that these results are based the original coupled model ("Model Type 1"). However, two other cases of interest were also examined for the seismic event with a 2,000-year return period, using the best estimate soil profile data. In one case ("Model Type 2"), the ground surface preparation with compacted aggregate and soil-cement layers was removed from the coupled model. In the other case ("Model type 3"), the dead loads of the seven adjacent casks and neighboring pads were included in the coupled model. The maximum horizontal sliding displacements of the cask for both additional cases for the 2,000-year return period event were determined to be less than those obtained using the original coupled model. This is shown in Table 8 of the Final Report, Rev. 1 (page 30).

Q14. Based on the maximum horizontal cask sliding displacements predicted by the model, is the collision of adjacent casks likely to occur?

A14. (VKL) No.

Q15. Please provide the basis for this conclusion.

A15. (VKL) The separation distance between neighboring casks is 47.50 inches. Half of this distance, or 23.75 inches, is regarded as the cask collision criterion. Inasmuch as maximum displacements under the design basis 2,000-year earthquake is 3.98 inches, no cask collisions were found to occur. Further, no collisions were found to occur at the PFS site for the 1971 San Fernando earthquake, Pacoima Dam record, for which the maximum displacement was 3.00 inches. Similarly, under 10,000-year seismic conditions, the maximum displacement was 15.94 inches, which is less than the collision criterion of 23.75 inches. Thus, even under the beyond-design basis 10,000-year event conditions, cask collisions were not found to occur.

Q16. What does the coupled model predict as the maximum cask rotation with respect to the vertical axis of the cask?

A16. (VKL) With respect to the 2,000-year return period seismic event, the analysis results indicate that the maximum cask rotation in either horizontal direction with respect to the vertical axis is equal to or less than 0.03 degrees, using a coefficient of friction of 0.20 for the cask/pad interface. Further, using a coefficient of friction of 0.80, in order to maximize the amount of cask rotation, results in a maximum cask rotation of about 0.22 degrees in the east-west direction and about 0.40 degrees in the north-south direction, with respect to the vertical axis, for the 2,000-year earthquake. In sum, the maximum cask rotation, with respect to the vertical axis, is equal to or less than 0.40 degrees under 2,000-year return period seismic conditions.

With respect to the 1971 San Fernando Earthquake (Pacoima Dam record), the maximum cask rotation in either horizontal direction with respect to the vertical axis, using a coefficient of friction for the cask/pad interface of 0.20, results in a maximum cask rotation with respect to the vertical axis, of 0.02 degrees in the east-west direction and 0.01 degrees in the north-south direction. Further, using a coefficient of friction of 0.80, in order to maximize the amount of cask rotation, results in a maximum cask rotation of 0.06 degrees in the east-west direction and 0.07 degrees in the north-south direction for the 1971 San Fernando Earthquake (Pacoima Dam record). In sum, the maximum cask rotation, with respect to the vertical axis, is equal to or less than 0.07 degrees for the 1971 San Fernando Earthquake (Pacoima Dam record).

With respect to the 10,000-year return period seismic event, the maximum cask rotation in either horizontal direction with respect to the vertical axis, using a coefficient of friction for the cask/pad interface of 0.20, results in a maximum cask rotation with respect to the vertical axis, of 0.10 degrees in the east-west direction and 0.05 degrees in the north-south direction. Further, using a coefficient of friction of 0.80, in order to maximize the amount of cask rotation, results in a maximum cask rotation of 0.65 degrees in the east-west direction and 1.16 degrees in the north-south direction, for the 10,000-year earthquake. In sum, the maximum cask rotation, with respect to the vertical axis, is equal to or less than 1.16 degrees even under 10,000-year return period seismic conditions.

Q17. Based on the maximum cask rotation predicted by the model, is cask tipover likely to occur during either the 2,000-year or 10,000-year return period seismic events?

A17. (VKL) No.

Q18. Please provide the basis for this conclusion.

A18. (VKL) The cask rotation that is associated with tipover is approximately 29 degrees. A rotation of less than 29 degrees would be insufficient to result in tipover of a loaded HI-STORM 100 cask.

Q19. How much movement of the cask in the vertical direction did your analyses predict?

A19. (VKL) A detailed evaluation of cask movement in the vertical direction was conducted. This evaluation indicates that the cask does not experience much displacement in the vertical direction in any of the three seismic events. The cask base is never entirely lifted off the top surface of the pad throughout the seismic event with a 2,000-year return period or the 1971 San Fernando Earthquake (Pacoima Dam record). Further, during either the 2,000-year return period seismic event or the 1971 San Fernando Earthquake (Pacoima Dam record), the maximum vertical displacement at any location of the cask base is much less than 1 inch above the top surface of the pad.

During the seismic event with a 10,000-year return period, the analysis results reveal that the cask base will entirely lift off the top surface of the pad by a maximum 0.26 inches, for a total duration of less than 0.30 seconds. Detailed examinations of the analysis results also indicate that the maximum vertical displacement at any point along the perimeter of the cask base is less than 2.7 inches above the top surface of the pad, for the 10,000-year event.

Q20. In your analysis, did you reach any conclusions as to the importance of the dynamic coupling or soil-structure interaction ("SSI") effect of the cask with the soil foundation?

A20. (VKL) Yes. As discussed in section 4.1 of the Final Report, Rev. 1 (pages 27-29), the dynamic coupling or SSI effect of the cask with the soil foundation was examined in detail, using acceleration results in the east-west direction for the governing case. The model analyses indicate the presence of a significant SSI effect, as shown in Figures 17 through 19 in the Final Report, Rev. 1 (pages 34-35). More specifically, as shown in these Figures, when the acceleration results at four locations on the soil surface are compared to the acceleration results at various depths along the central axis of the pad, noticeable differences in acceleration are observed. The SSI effect is further demonstrated by plotting the corresponding response spectra in Figures 20a through 22b. These differences demonstrate the presence of the SSI effect and justify the development of the coupled finite element model in the Staff's research effort.

Q21. What is your overall conclusion with respect to stability of the freestanding HI-STORM 100 casks at the proposed PFS Facility, and the potential for cask sliding, collision, and tipover?

A21. (VKL, JG) For the reasons discussed above and in the Final Report, Rev. 1, it is our conclusion that excessive cask sliding or cask collisions will not occur. Further, it is our conclusion that cask tipover will not occur during either a 2,000-year re'urn period or 10,000-year return period seismic event at the PFS site. Accordingly, we believe that Part D.1.i. of Unified Contention Utah L/QQ does not present a valid concern.

A22. Does this conclude your testimony?

A22. Yes.

Vincent K. Luk

EDUCATION:

Ph.D., Theoretical and Applied Mechanics, Northwestern University, 1978
M.S., Theoretical and Applied Mechanics, Northwestern University, 1975
B.S., Civil Engineering, University of Mississippi, 1974

WORK EXPERIENCE:

December 1993 to Present

Principal Member of Technical Staff
Nuclear Technology Programs Department, 6420
Sandia National Laboratories / New Mexico

- Team Leader of the Structural Analysis and Evaluation Team for an NRC Integrated Vulnerability Assessment Project. This project examines the vulnerability and structural integrity of nuclear power plants subjected to external high-energy impacts.

- Principal Investigator for the International Nuclear Energy Research Initiative (INERI) Project on "Condition Monitoring through Advanced Sensor and Computational Technology." This project is an international joint project with Korea Atomic Energy Research Institute (KAERI) of South Korea. This project focuses on developing and demonstrating advanced sensor and computational technology for continuous monitoring of the condition of components, structures, and systems in advanced and next generation nuclear power plants.

- Task Leader in the Nuclear Energy Research Initiative (NERI) Project on "Development of Advanced Technologies to Reduce Design, Fabrication and Construction Costs for Future Nuclear Power Plants." This task focuses on investigating the feasibility of developing the design-to-analysis tool to be used to enhance the efficiency of design/analysis cycle.

- Principal Investigator of an NRC project to examine the seismic behavior of freestanding dry cask storage systems subjected to earthquake excitations. In this project, coupled finite element models consisting of casks, concrete pad, and soil foundation were developed to investigate the nonlinear dynamic seismic behavior of cask systems and the soil-structure-interaction effect.

- Lead Engineer for the Steel Containment Vessel Project. This project is a part of the Cooperative Containment Program between Nuclear Power Engineering Corporation (NUPEC) of Japan and US NRC. Responsibilities include overall project management and coordination to conduct an overpressurization test of a scale model of a steel containment vessel and to perform finite element analyses to simulate model responses.

- Analysis Coordinator for NUPEC/NRC Cooperative Containment Program. Responsibilities include defining and monitoring pretest and posttest analysis tasks for simulating structural responses of scale models of steel and prestressed concrete containment vessels under severe pressure loading conditions. Additional assignments are to coordinate the Round Robin analysis activities that involve the participation of various US and international groups to perform independent analyses in pretest predictions and post-test evaluation.

April 1985 to November 1993 | Senior Member of Technical Staff
Advanced Munitions Department, 9723
Sandia National Laboratories / New Mexico

- Developed analytical penetration models based on spherical and cylindrical cavity-expansion approximations to predict dynamic loads on projectiles, projectile trajectories, and final penetration depths. Penetration problems included penetration and perforation of aluminum and steel targets, penetration of concrete and soil targets, and perforation of concrete slabs.

- Conducted laboratory-scale ballistic tests and full-scale sled-track tests.

- Team Coordinator for Penetration Technology Team, starting in 1991. Responsibilities included serving as a single point of contact for penetrator technology project activities, to interface with customers, to develop new projects and expand customer base, and to provide team networking of communication and interaction among participants of different disciplines.

- Project Manager for the MOU (Memorandum of Understanding) Tandem-Rod Kinetic Energy Projectile Project. This project involved activities from concept definition, system design and analysis, hardware design and fabrication, to the eventual system demonstration for dual penetrators as an anti-armor system.

- Project Manager for the MOU Penetration Technology Project. Principal project tasks included advancement of penetration technology in the common interests of weapon programs for DOE and DoD laboratories.

- Project Manager for the DOE/DP Penetrator Tech Base Project. Project tasks included providing penetrator technology support to the Defense Program to broaden operational options for the development of future penetrating weapons and developing computational codes as reliable weapon design tools.

January 1981 to March 1985 | Senior Staff Engineer
Engineering Mechanics Group
Franklin Research Center, Philadelphia, PA

- Performed structural analysis using finite element techniques on nuclear power plant containment vessel, condenser waterbox flange, valve/actuator assemblies, fan pedestals, and cartridge and barrel assembly of machine guns.

- Performed stress analyses, fatigue evaluation, and heat transfer analyses.

- Section Leader in an NRC project to review the feasibility and adequacy of the kinetic expansion process used to repair damaged tubes and to evaluate the performance of expanded tubes in the Once-Through Steam Generators at Three Miles Island Nuclear Power Station (TMI-1).

July 1978 to December 1980 — Stress Analyst
Joseph Oat Corporation
Camden, NJ

- Performed seismic analysis and design of heat exchangers and pressure vessels.
- Performed water-hammer analysis of piping system in heat exchangers for flow-induced vibration during start-up condition.
- Performed response spectra analysis and impact evaluation of new and intermediate fuel storage racks.
- Performed thermal fatigue analysis of tubesheets in regenerative heat exchangers.
- Project Leader in an EPRI project to conduct an experimental study on feedwater heater tube erosion; a laser doppler velocimeter was used to measure 3-dimensional turbulent flow profile inside the inlet header of a plexi-glass model of feedwater heater.

September 1974 to June 1978 — Research Assistant
Northwestern University
Evanston, Illinois

- Major fields: elasticity, fracture mechanics and solid contact problems.
- Fracture analysis of spot-welded elastic layers subjected to shear loads.
- Fracture analysis of a cylindrical cavity containing a circumferential edge crack.
- Three-dimensional stress analysis of an elastic half-space containing a partially embedded finite rod.

Awards and Honors:

Sandia National Laboratories

- Award for Excellence in November 1999 for outstanding work in executing the PCCV Round Robin Analysis task.
- 1996 President's Quality Award – Turquoise Award as a member of the NUPEC/NRC Containment Project Team.
- Award for Excellence in June 1992 for outstanding leadership of the Tandem Rod Project that resulted in high praise from the project sponsor.
- Award for Excellence in April 1993 for exceptional leadership of the EPW Tech Base Project.

Northwestern University

- Walter P. Murphy Fellowship in 1974-1975.
- Royal E. Cabell Fellowship in 1977-1978.

University of Mississippi

- Foreign Student Scholarship in 1971-1974.
- Faulkner Concrete Pipe Company Scholarship in 1972-1974.
- Recipient of Taylor Medal in Civil Engineering in 1973.
- Recipient of Taylor Medal Citation in Civil Engineering in 1974.
- President of the Student Chapter of the American Society of Civil Engineers in Senior Year.
- Recipient of the Outstanding Civil Engineering Student Award in 1974.
- Student Marshall for the School of Engineering in the 1974 Commencement.
- Chi Epsilon, Tau Beta Phi and Phi Kappa Phi

Professional Society Affiliations:

Member, American Society of Mechanical Engineers.

Journal Publications:

1. L. M. Keer and V. K. Luk, "Stress Analysis of an Elastic Layer Attached to an Elastic Half Space of the Same Material," International Journal of Engineering Science, Vol. 14, pp. 735-747, 1976.

2. L. M. Keer, V. K. Luk, and J. M. Freedman, "Circumferential Edge Crack in a Cylindrical Cavity," Journal of Applied Mechanics, Vol. 99, No. 2, pp. 250-254, 1977.

3. V. K. Luk and L. M. Keer, "Stress Analysis for an Elastic Half Space Containing an Axially-Loaded, Rigid Cylindrical Rod," International Journal of Solids and Structures, Vol. 15, pp. 805-827, 1979.

4. V. K. Luk and L. M. Keer, "Stress Analysis of a Deep Rigid Axially-Loaded Cylindrical Anchor in an Elastic Medium," International Journal for Numerical and Analytical Methods in Geomechanics, Vol. 4, pp. 215-232, 1980.

5. K. P. Singh and V. K. Luk, "An Approximate Analysis of Foundation Stresses in Horizontal Pressure Vessels," Journal of Engineering for Power, Vol. 102, No. 3, pp. 555-557, 1980.

6. K. P. Singh, M. Holtz, and V. K. Luk, "On Minimization of Rad-Waste Carry-Over in an N-Stage Evaporator," Heat Transfer Engineering, Vol. 5, Nos. 1-2, pp. 68-73, 1984.

7. M. J. Forrestal, Z. Rosenberg, V. K. Luk, and S. J. Bless, "Perforation of Aluminum Plates with Conical-Nosed Rods," Journal of Applied Mechanics, Vol. 54, No. 1, pp. 230-232, 1987.

8. V. K. Luk and M. J. Forrestal, "Penetration into Semi-Infinite Reinforced-Concrete Targets with Spherical and Ogival Nose Projectiles," International Journal of Impact Engineering, Vol. 6, No. 4, pp. 291-301, 1987.

9. M. J. Forrestal, V. K. Luk, and H. A. Watts, "Penetration of Reinforced Concrete with Ogival-Nose Penetrators," International Journal of solids and Structures, vol. 24, No. 1, pp. 77-87, 1988.

10. M. J. Forrestal and V. K. Luk, "Dynamic Spherical Cavity-Expansion in a Compressible Elastic-Plastic Solid," Journal of Applied Mechanics, Vol. 55, No. 2, pp. 275-279, 1988.

11. M. J. Forrestal, K. Okajima, and V. K. Luk, "Penetration of 6061-T6 Aluminum Targets with Spherical, Ogival, and Conical Nose Rods," Journal of Applied Mechanics, Vol. 55, No. 4, pp. 755-760, 1988.

12. V. K. Luk and M. J. Forrestal, "Comments on 'Penetration into Semi-Infinite Reinforced-Concrete Targets with Spherical and Ogival Nose Projectiles'," International Journal of Impact Engineering, Vol. 8, No. 1, pp. 83-84, 1989.

13. M. J. Forrestal, A. J. Piekutowski, and V. K. Luk, "Long-Rod Penetration into Simulated Geological Target at an Impact Velocity of 3.0 km/s," Proceedings of the 11th International Symposium on Ballistics, Brussels, Belgium, May 9-11, 1989.

14. M. J. Forrestal, V. K. Luk, and N. S. Brar, "Perforation of Aluminum Armor Plates with Conical-Nose Projectiles," Mechanics of Materials, Vol. 10, No. 1-2, pp. 97-105, 1990.

15. V. K. Luk, M. J. Forrestal, and D. E. Amos, "Dynamic Spherical Cavity-Expansion of Strain-Hardening Materials," Journal of Applied Mechanics, Vol. 58, No. 1, pp. 1-6, 1991.

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Thesis and Dissertation:

1. "Fracture Analysis of a Spot Welded Elastic Layer in Shear," M.S. Thesis, Northwestern University, August 1975.

2. "Elastostatic Load-Diffusion Characteristics of Embedded Axially-Loaded Cylindrical Structures," Ph.D. Dissertation, Northwestern University, June 1978.

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While working at the NRC, Mr. Guttmann was responsible for reviewing and approving the computer codes used by the nuclear industry for transient and accident analysis. He represented the Office of Nuclear Reactor Regulation (NRR) on the Advanced Code Review Committee, the Loss of Fluid Test Facility, and the Semiscale Test Facility. Mr. Guttmann performed independent analyses of plant operating events, including regulatory responses to the TMI-2 accident. He was a member of the BWR Bulletins and Orders Task Force that reviewed the ramifications of the TMI-2 events for boiling water reactors. He reviewed and approved emergency operator procedures for PWR designs and performed quality assurance inspections. Mr. Guttmann developed standard review plans for analyzing reactor transient and accident events, developed regulatory guidance and NUREG documents for implementing Risk-Informed In-Service Testing of Piping, and was on the task force and project manager for developing Risk-Informed regulatory guidance documents (i.e., RG-1.174, -1.175, - 1.176, -1.177, and 1.178).

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